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THE PREPARATION OF METALS IN A COMPACT FORM BY PRESSING AND SINTERING

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The metals tungsten, molybdenum, tantalum etc. can be relatively easily prepared in powder form. The powder, however, due to the high melting point of the metals, cannot be converted into compact form by melting and casting. The preparation of the compact metals must therefore be carried out by the methods of powder metallurgy, the main particulars of which we shall here discuss. A general discussion is then given of the preparation and working of ductile tungsten for the electric lamp industry, and the preparation and application of so-called "hard cemented carbides". In certain applications use is also made of the great porosity which sintered metals may possess.

The development of the electric lamp industry brought up the problem of the preparation in wire form of metals with very high melting points such as osmium, tantalum, molybdenum and tungsten. The preparation of these metals in powder form presented no great difficulties, but the conversion of the powder into a compact form met with great difficulties. The high melting points made it impossible to achieve this end by the ordinary methods of melting and casting, and led to attempts to cement or bake together the particles of which the metals in powder form consist, at temperatures below the melting point. In the practical application of this method two operations are found necessary in most cases: a treatment at ordinary temperature by which the particles are made to form a cohering mass, and a heating of this mass at a high temperature, the socalled sintering process, the purpose of which is to considerably increase the strength and cohesion of the mass.

The treatment at ordinary temperature, in the case of the preparation of the earliest osmium and tungsten wires, consisted in the cementing together of the particles with the help of an adhesive substance. It was, however, quickly realized that the desired result can be obtained without the use of a binder, by pressing the pure powder in a mould.

The pressing of the dry metal powders to give coherent masses

Compact metals are not in general single crystals (even when they are obtained by way of the molten state), but conglomerations of many larger or smaller crystals which are held together by cohesive forces. These forces are in many cases of the same order of magnitude as the forces which hold a single crystal together. In principle it must be possible to cause these cohesive forces to act by bringing the particles which make up the metal powder into close enough contact with each other. The action of these forces only becomes appreciable at very short distances.

As to the practical execution of this process, the following difficulties must be noted:

1. The particles will generally have such a shape that the surface of mutual contact is very small and the porosity therefore large.
2. The metals in the air are covered with oxide films which are often only one molecule thick, but which hinder the action of the cohesive forces.
3. The structure of the outer layers of atoms of a bare metal surface will be different from that of the outer layers of atoms of a crystallite in the interior of a cast metal object. After bringing of the particles into more intimate contact (even in the absence of oxide films) the cohesive force will therefore in general be smaller per unit of surface of actual contact than that between the crystallites in a cast metal.

These objections are partially met when high pressures are applied in making the separate par-

ticles cohere. A not inconsiderable deformation of the particles occurs which appreciably increases the total surface of contact. Moreover, many particles rub against each other during the pressing, whereby the oxide films are rubbed off at many points, and local temperature increases of very short duration occur which make possible a partial regrouping of the metal atoms at the points of contact. It is indeed found to be possible to press articles from dry metal powders by the application of high pressures, which articles do not fall to powder again after the pressure is lowered. The strength is in most cases, however, only small, because the three above-mentioned opposing factors are rendered only partially inactive by the pressing: the total surface of contact after pressing is still relatively small, while in addition the cohesion per unit of surface of contact is smaller than between the crystallites in a cast metal, due to the fact that the surface films are still present between the particles at many spots, and at other spots where this is no longer true, that atom arrangement has not yet been attained which occurs at the boundary between two grains in a cast metal. A heat treatment is necessary in order to cause the structure to approach more nearly that of a cast metal.

The heating of pressed objects

When pressed objects are heated considerable strengthening occurs already at a relatively low temperature. Rods of tungsten, for example, which were so weak after being pressed from the powder that they could not be handled without breaking, already have such a great strength after being heated in hydrogen at 1 000° C, that they can be clamped into the current supply terminals for the actual sintering process. The cause of this strengthening must be sought in a rearrangement of the atoms at the points of contact and in a reduction of the oxide films still present.

The actual sintering, which takes place at a much higher temperature, is accompanied by considerable shrinkage and a corresponding decrease of the porosity (during the preliminary sintering at 1 000 °C no appreciable shrinkage takes place). The mechanism of the shrinking may be conceived in two ways. In the first place it is reasonable to suppose that the influence of the large amount of free surface is manifested in such a way that under the influence of the surface tension as driving force a plastic deformation of the grains occurs, whereby they are as it were "sucked" into the open spaces. The resistance which metals offer to plastic deformation becomes smaller with increasing temperature, and in agreement with the foregoing it is found that the temperature at which sintering occurs is higher, the less deformable (harder) a metal is. It may, however, also be supposed that the presence of the large internal surface in the pressed objects results in a transfer of material at sufficiently high temperature by surface diffusion, whereby the metal atoms move over the surfaces of the particles to spots where their potential energy is the lowest. It is indeed known that the atoms in the surface of a metal already possess considerable mobility in that surface at temperatures lying below those at which the metal melts or evaporates to any noticeable degree, because these movements require a much smaller amount of energy than evaporation. It is probable that both of these phenomena play a part in the sintering of metals.

If the particles of which a pressed object is made up were grains without faults, the sintering would probably proceed in a quite uncomplicated manner, and would perhaps only be accompanied by or followed by a shifting of the crystal boundaries due to the fact that during and after the sintering some grains grew at the expense of others [1]). We have, however, already seen that the particles are deformed during the pressing. Moreover, their previous history (method of preparation) is in some cases of such a nature that even before the pressing they have an unstable structure. The result is that upon heating the pressed objects recrystallization phenomena occur, *i.e.* in the particles or at the boundary between two particles new crystal nuclei occur which grow at the expense of the deformed or otherwise structurally unstable metal until they encounter other newly formed crystallites. Coalescence of the new crystals formed to give larger units often follows this recrystallization. In many cases the beginning of recrystallization seems to introduce the sintering process, in other cases the sintering entirely or partially precedes the recrystallization.

As a result of the recrystallization process and the

[1]) This phenomenon whereby in a metal without tensions certain crystals grow at the expense of others, and where the internal energy decreases by reduction of the surface of the crystallite boundaries, is usually called coalescence. In order to avoid confusion between the ideas of sintering and coalescence, it must be emphasized that sintering can only occur in a porous substance, and need not necessarily be accompanied by an increase in size of the grains, but by a change in their shape. Coalescence or grain growth can occur not only in compact but also in porous metal, and need not in the latter case be accompanied by a decrease in the porosity; the phenomenon is characterized only by a decrease in the number of individual grains.

grain growth mentioned above, the size of the crystallites in the sintered products is often very much greater than the size of the particles of the original powder. The pores which are still present now lie for the most part within the crystallites. This remaining porosity can only be removed by very strenuous mechanical working.

The influence of gases on the process of sintering

The phenomena which occur during the heating of masses of pressed metal powder can in many cases be influenced by the gases freed from the metal and by gases expressly introduced from the outside. The gas liberated from the metal may come from one or more of the following sources:

a) Gas adsorbed on the surface of the particles
b) Gas dissolved in the metal
c) Chemically bound gas
d) Gases enclosed between the metal particles during pressing
e) Gases formed by a chemical reaction between foreign substances present in the metal. Technical iron and nickel, for instance, which are also used in certain cases for the preparation of sintered products, always contain appreciable amounts of carbon in a free state or in the form of carbides as well as oxygen, dissolved and in the form of oxides. Upon heating, carbon dioxide and carbon monoxide are formed, and these gases are liberated in large quantities.
f) Gases freed from layers of grease on the metal surfaces.

If the objects are pressed at a very high pressure, it may be (especially in the case of soft metals) that the metal is compressed in such a way that many cavities are entirely closed to the outside or that they are connected to the outside only by very narrow channels. The gases freed may then cause very high internal pressures, and thereby oppose the sintering process and sometimes even cause swelling instead of shrinking.

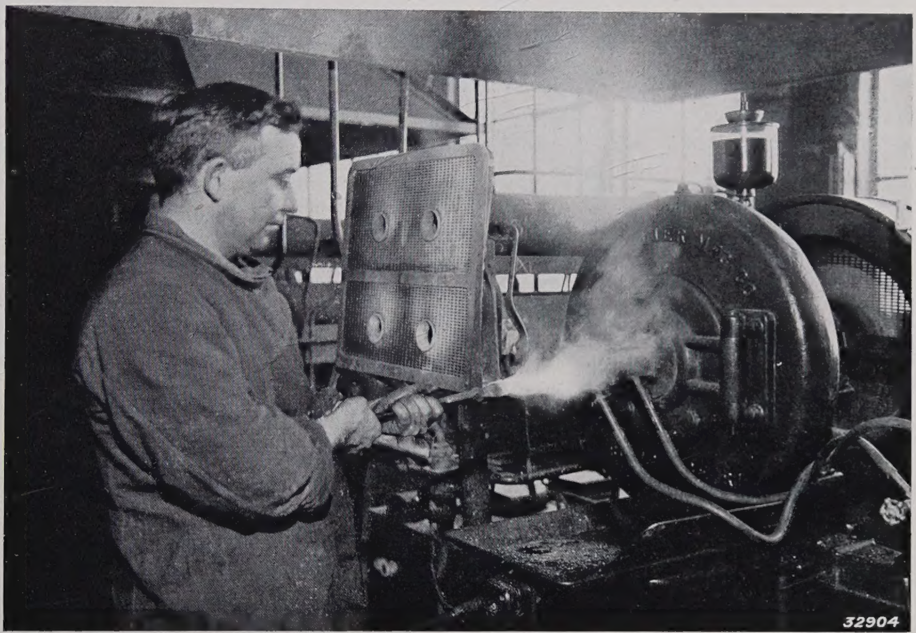


Fig. 1. After sintering the tungsten rods are first treated in a hand swaging machine. The rod, heated to a high temperature, is gripped with tongs and introduced between the rapidly moving hammers (see fig. 2). This treatment brings about a decrease in the thickness and an increase in length. As soon as the length has increased sufficiently the rod is worked by a more automatic swaging machine. Beside the hand swaging machine in the photograph may be seen the electric furnaces in which the rods are heated.

Gases introduced from the outside serve to protect the pressed objects against oxidation during heating. Thus for example the sintering of tungsten and molybdenum is carried out in pure hydrogen, whereby the hydrogen also carries out the important function of reducing the oxide films. Metals which form such stable oxides that the oxide films cannot be reduced to metal by any gas, can only be obtained in a pure form by sintering when the oxide has a higher vapour tension than the metal, or when it has an appreciable oxygen dissociation pressure at the temperature of sintering. These conditions are fulfilled by tantalum which can therefore be obtained in pure state by sintering in a high vacuum. Thorium, on the other hand, forms

an oxide which again cannot be reduced to the metal by hydrogen, but which moreover has a lower vapour tension than the metal, and does not dissociate appreciably below the melting point of thorium. The result is that while this metal can be obtained in a ductile form by the methods of powder metallurgy, it cannot be obtained in an oxygen-free state. After the sintering the oxide is present in the form of mechanical inclusions in the metal. Still more unfavourable are the relations in the case of titanium, zirconium and hafnium, whose oxides, moreover, dissolve in the excess metal at the sintering temperature, so that the metal loses the greater part of its workability. It was indeed necessary to apply quite different methods in order to obtain these latter metals in a completely ductile form (see Philips techn. Rev. **3**, 345, 1938.)

After the foregoing general considerations on powder metallurgy we shall in the following deal with several of the most important applications.

The preparation of ductile tungsten

The tungsten in powder form which is used as raw material is prepared by reducing tungsten oxide WO_3 with hydrogen. This reduction is carried out under conditions such that the metal is obtained in the form of particles only a few microns in diameter (1 micron = 10^{-3} mm). The powder is pressed in steel forms by means of a hydraulic press to rods with a square cross section. After the previously mentioned preliminary sintering process in hydrogen at a relatively low temperature, follows the actual sintering in which the rods are heated by the passage of current to above 3 000° C (the melting point of tungsten lies at about 3 400° C). Such great shrinkage occurs during this process that the specific weight rises from about 12 to about 18, and the length after sintering is only about 85 per cent of the original length. In the mechanical working (see below) further compacting of the metal occurs, whereby the specific weight finally rises to that of non-porous tungsten, namely 19.35. The size of the crystals in the rods after sintering is considerably greater than that of the particles of the original powder. Important crystallization phenomena thus take place in the rods in the manner described above.

The sintered rods are already very strong, but are still extremely brittle, at least at an ordinary temperature. At high temperatures, on the other hand, they are found to possess satisfactory ductility so that it is possible to work them into wire. In the first treatment, use is made of swaging machines (*fig. 1*) in which two hammers, having semi-cylindrical depressions rotate about the axis of the rod and strike it about 10 000 times per minute (*fig. 2*).

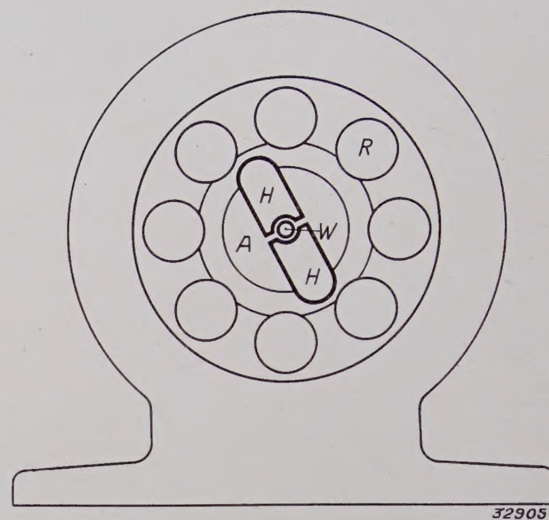


Fig. 2. Diagram of a swaging machine. In the hammer head A is a groove in which the hammers H can move in a radial direction. When in use the head A rotates with great velocity, with the result that the hammers are forced away from each other by the centrifugal force. In doing this they strike the rollers R, an even number (usually 8 or 10) of which are situated in a ring around the hammer head. The hammers are hereby thrown forcibly against each other 8 or 10 times per revolution. The heated tungsten rod W is introduced between the hammers and thus receives blows whose number is determined by multiplying the number of revolutions by the number of rollers. By using a series of hammers with increasingly smaller bore the rod can be hammered thinner and thinner.

The sintered rods are heated in an electric oven and then passed slowly between the hammers whereby the thickness decreases and the length increases correspondingly. In order to convert the rods, which originally have, for example, a square cross section of 15·15 mm², into wire 1 mm thick, this treatment must be repeated many times. Hammers, with steadily decreasing size of depression, are used. In contrast to practically all other metals tungsten becomes more ductile the more it is worked. The explanation of this must be sought in the weakness of the crystal boundaries which causes the crystals in a sintered rod to break away from each other upon attempts to deform it at low temperatures. By the working, however, the crystals, which originally had approximately equal dimensions in all directions, are stretched in the direction of the axis of the rod. As the rod becomes thinner, it assumes more and more a fibrous structure, and it is this change in structure which gives the wire its increasing ductility.

Because of the increase of ductility the working temperature can be steadily lowered. This is also essential in order to avoid a recrystallization which would give back to the wire its original brittleness,

and the temperature at which recrystallization occurs decreases with increasing deformation.

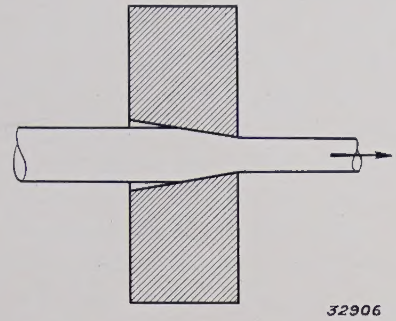


Fig. 3. Diagram of the wire drawing process.

After the swaging the tungsten wire is converted by a drawing process into still thinner wire. The dies possess a conical bore whose smallest diameter is of course somewhat smaller than that of the wire. *Fig. 3* shows a diagram of such a die. The wire is drawn through it by means of a spool, which is fastened to a shaft driven by electric power, and upon which the wire is wound (*fig. 4*). For the larger

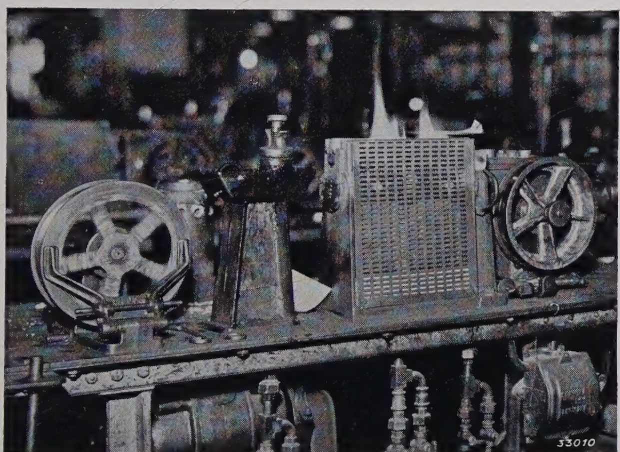


Fig. 4. The photograph shows a drawing bench as used in the manufacture of tungsten wire. On the left is the spool from which the wire is unwound. The wire passes first through a container with graphite lubricant (suspension of graphite in water). It is then heated by a gas burner so that the water evaporates and part or all of the graphite remains on the wire. When hot the wire passes through the die to the spool shown on the right.

thickness use is made of dies of so-called tungsten carbide, which material like tungsten is also prepared by pressing and sintering (see below). For the smaller thickness diamond dies must be used. As a result of the drawing the ductility of tungsten increases to a still greater extent, so that it is possible to reduce still further the working temperature. In the way described it is possible to make tungsten wire with a thickness of only 8 microns (0.008 mm). The wire must pass through a large number of dies before such a final diameter is reached, because, due to the limited tensile strength of the wire, the diameter can be only relatively slightly reduced by a single drawing. Directly before the passage through each die the wire is heated with gas burners to the desired temperature. Graphite is used as lubricant in the drawing and also serves to protect the tungsten surface from oxidation.

In the manner described, from a pressed and sintered tungsten rod weighing 1.5 kg about 1 000 km of wire 10 microns thick is obtained.

When the tungsten wires obtained by hammering and drawing are used in electric lamps, recrystallization phenomena occur at the first heating to a high temperature. The structure to which this recrystallization leads, and which determines for a large part the life and quality of the lamp, can be influenced by adding certain chemicals to the tungsten powder.

The preparation of molybdenum and tantalum in a ductile form

Several other metals with a high melting point besides tungsten, which are also used technically, are also prepared in compact pieces by the methods of powder metallurgy.

The most important of these are molybdenum with a melting point of 2 600° C and tantalum with a melting point of 3 000° C. These melting points are too high for the successful preparation of the compact metals by melting and casting.

The preparation of molybdenum powder and molybdenum rods takes place in practically the same way as described above for tungsten. The rods can also be worked to wire and sheet. Molybdenum is extensively used in the manufacture of electric lamps and radio valves: in wire form chiefly as support wires for the tungsten wires and coils of electric lamps, in sheet form chiefly as anode of transmitting valves. A very well known use of molybdenum wire is as heating element in electric furnaces for very high temperatures.

Metallic tantalum can be obtained in powder form, for example by the reduction of potassium tantalum fluoride with sodium or by electrolysis of this compound in the molten state. The rods pressed from the powder are sintered in a high vacuum because, among other reasons, tantalum forms hydrides with hydrogen. During the sintering the driving off of the dissolved hydrogen present in the powder and of chemically bound oxygen is very important. Like molybdenum tantalum is used in discharge tubes, for instance in the form of anodes in transmitting valves. Furthermore it is used as a

corrosion resistant material in the artificial silk industry, for example.

The preparation of hard cemented carbides

Various metal carbides possess a very great hardness. One of the hardest is tungsten carbide, having the composition WC. Its hardness is not very much less than that of the diamond. When the electric lamp industry was seeking a suitable material to replace the expensive diamond in the manufacture of dies, this material was chosen. In a pure state it was found to be unsuitable because, like metallic tungsten, the boundaries of the crystallites are not stable and the material is therefore brittle. Better results could be expected if it were possible to prepare the material in the form of large single crystals. The solution of the difficulty was, however, sought in a different direction, and usable articles have successfully been made by beginning with very fine tungsten carbide powder and cementing the particles of this together with a metallic binder by the methods of powder metallurgy. In other words the grain boundaries were replaced by a layer of a binder which possesses a sufficient degree of ductility and strength. The hard cemented carbides are therefore strictly speaking no metals, since they consist almost entirely of carbide to which a small amount of free metal has of necessity been added. The carbides in question have, however, metallic characteristics in many respects (electrical conductivity, to name an example). As binder a metal is used which has only a very slight affinity to carbon (cobalt, for instance).

Tungsten carbide is obtained by heating intimate mixtures of fine tungsten powder and carbon in a suitable gas atmosphere. The carbide formed is mixed with the auxiliary metal serving as binder, and pressed into larger pieces in a steel mould. The objects pressed in this way are usually presintered in hydrogen at a relatively low temperature. This presintering serves to make the cohesion of the pieces so much greater that they may be given the desired form. In this condition the material can for example be worked on a lathe. After the pressing alone the cohesion is still too low for this, while after the final sintering the hardness renders such working impossible. At this stage, however, the articles cannot be given their exact final shape since a shrinkage of nearly 20 per cent occurs during the actual sintering. This sintering takes place at a temperature below the melting point of the pure binder metal. The hardness is so great after the final sintering that the shape can only be changed by grinding or polishing with the hardest abrasives.

From experiments by various research workers it has, moreover, been found that when cobalt is used as binder the case is not one of ordinary sintering, since this binder melts during the heating. A small amount of the tungsten carbide dissolves in the metal during sintering, and causes a lowering of the melting point. The relatively small amount of liquid formed is taken up as by a sponge by the porous mass, with simultaneous decrease in volume, so that the porosity after sintering is so low as to be inappreciable. This is demonstrated by *fig. 5*, while the structure of the hard cemented carbide is shown in *fig. 6* [2]).

In this case, where sintering temperature is not

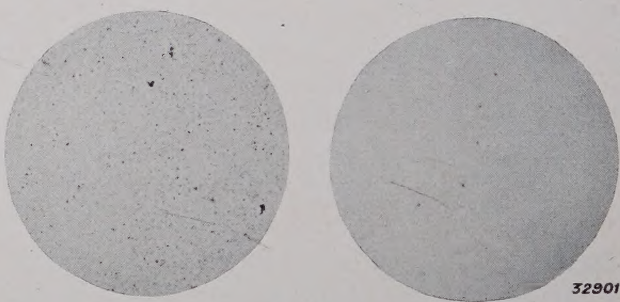


Fig. 5. In order to examine the porosity of tungsten carbide alloys, a plane surface is ground on a sample in much the same way as is customary in the grinding of diamonds. The polished surface is examined under a microscope with a magnification of 50 times. To the left may be seen a photomicrograph of a product sintered at too low a temperature, which has great porosity. On the right is that of a product sintered at the correct temperature which has almost no pores.

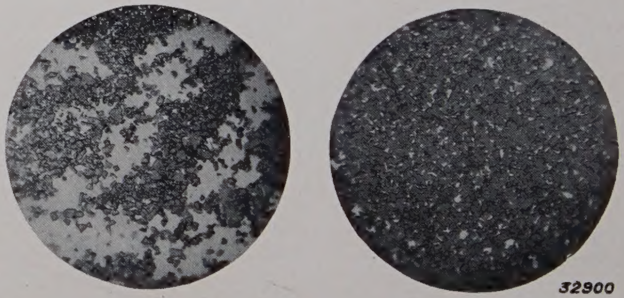


Fig. 6. By etching the polished surface of a piece of a tungsten carbide alloy in a suitable bath, the microstructure can be made visible under a magnification of, for example, 500 times. On the left is shown the structure of an alloy with too low a content of carbon (*i.e.* an alloy in which the tungsten carbide consists of a mixture of WC and W_2C). The tungsten carbide particles are here not distributed uniformly throughout the auxiliary metal in which at the sintering temperature an abnormally large amount of the tungsten carbide has dissolved. On the right may be seen the microstructure of an alloy with the correct amount of carbon (*i.e.* an alloy in which the tungsten carbide consists exclusively of WC). The carbide particles are regularly distributed throughout the base metal which acts as binder and which contains only little tungsten carbide in solution.

[2]) The samples and the photomicrographs were prepared by Mr. J. Romp.

high, it is also possible to combine pressing and sintering by pressing the mixture at the sintering temperature. Moreover this method offers the possibility to evite the preparation of tungsten-carbide by starting the pressing on sintering-temperature with a perfect mixture of tungsten, bindermetal and carbon. In this way the preparation of carbide, the pressing and the sintering are combined into one operation.

The most important applications of the above described hard cemented carbides lie in the sphere of metal working, where it is used in wire manufacture (see *fig.* 7 and 8) and in cutting, milling and boring operations. The composition depends upon the purpose for which it is to be used. The strength (tensile) increases with the content of binder, but the hardness decreases. In all of its applications, due to its relatively high price, only that part of the tool is made of carbide which is subject to wear during use.

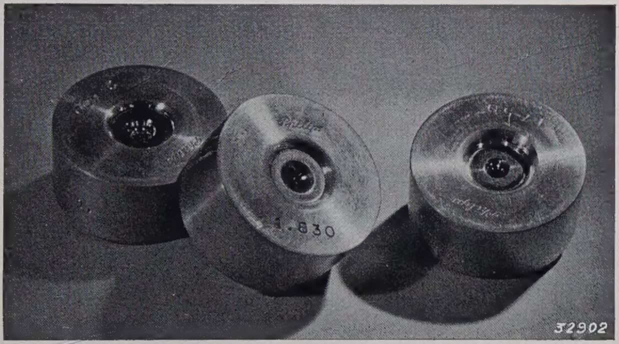


Fig. 7. Dies with a core of "hard cemented carbide".

When used as cutting tools tungsten carbide alloys are very suitable for the working of non-ferrous metals and also of cast iron. In the working of steel better results are obtained when the tungsten carbide is partially replaced by titanium carbide.

Different other hard carbides and also some borides, silicides and nitrides can be used in addition to the two mentioned carbides.

Several additional applications and possibilities of powder metallurgy

In the earliest applications of powder metallurgy (tungsten, molybdenum, etc.) the only aim was the best possible approximation of the results which would have been obtained by melting and casting if the melting points had not been too high. It was, however, quickly discovered that this new method, far from being merely a substitute for the older method, also offers possibilities which cannot be realized by melting and casting. As an example of such possibilities we have already mentioned the introduction of foreign chemicals into metallic tungsten with the object of influencing the crystal growth. In the case of metals which are obtained by way of the molten state it would be very difficult, if not impossible, to introduce such insoluble, non-metallic additions in fine and uniform dispersion. The cemented carbides discussed also constitute an example of products with a dispersion of the components which could not be obtained by melting and casting. The structure deviates so much from the equilibrium state that too long a sintering or too high a sintering temperature already produces a different (less favourable) final state which can no longer be converted into the desired one.

There are also examples of applications where use is made of the porosity which the sintered products all possess to a greater or less degree. (This porosity is an undesired phenomenon in the preparation of metals of high melting points, and attempts are made to reduce it to a mimimum by mechanical working). The most important application in which advantage can be taken of the porosity is formed by the so-called self-lubricating bearings. These are bearings, which are usually pressed from a mixture of copper and tin powder (for example 90 per cent copper + 10 per cent tin), and which after sintering have such a degree of porosity that they can absorb large quantities of oil (25 to 40 per cent by volume), and thereby obtain self-lubricating properties. It is clear that the porosity of these bearings must not only be great, but it must in addition be of such a nature that the pores are interconnected. This is achieved by beginning with powders prepared by electrolytic methods, whose particles are rather large and irregular in shape, and by mixing these powders with substances (stearic acid, for example) which evaporate during sintering and leave cavities. In addition to copper and tin the porous bearings often contain graphite, which is added to the powder mixture before pressing, in amounts of 1.5 to 4.5 per cent. The impregnation with oil takes place in heated oil baths. Especially when bearings must be installed in places which are difficult to reach, or when they must function under water, these products of sintering offer great advantages. The oil consumption, moreover, is much less than with ordinary bearings. A small increase in temperature or pressure exerted on the bearing causes the oil to come out of the bearing. Self-lubricating bearings have been manufactured in very large quantities

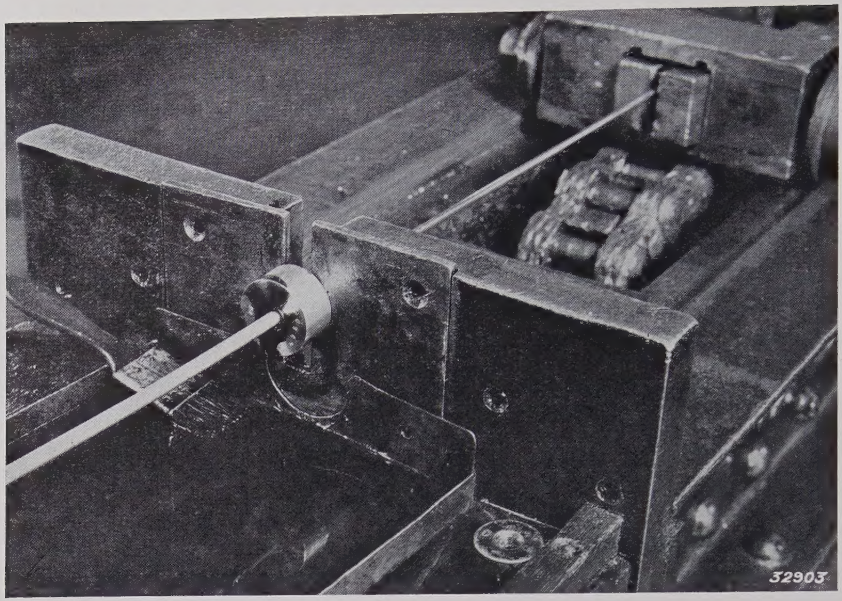


Fig. 8. A die with a "hard cemented carbide" core in use. It may clearly be seen in the photograph, that the wire has a smaller diameter after passing through the die.

in recent years, especially for the automobile industry.

The porosity of sintered metals also makes it possible to prepare new materials in which the properties of various metals are combined. This possibility is already in practical application in different types of electrodes for spot welding, where great strength at high temperatures and at the same time good electrical conductivity is required. Tungsten powder of a suitable particle size is pressed and sintered in such a way that very porous. but strong rods are obtained. These are heated in an atmosphere of hydrogen or in a vacuum and brought into contact with molten copper. The pores become filled with the copper. The copper content after this treatment is about 40 per cent. The electrodes obtained possess very great strength at high temperatures due to their tungsten framework, and due to their copper content they have a high conductivity for electric current.

ON IMPROVING OF DEFECT HEARING

by K. de BOER and R. VERMEULEN. 534.773

An apparatus is described which was developed for a particular case of partial deafness, and which satisfies very high requirements as regards the quality of reproduction. The requirement that the apparatus should be portable was not made. The frequency characteristic of the apparatus was adapted to the curve for the defective ear of the individual user. By making use of two microphones placed in an "artificial head", each of which supplies one head-phone, directional hearing has also been made possible. This is of great practical value in following general conversations and preventing disturbance by extraneous sounds.

In order to compensate for the decreased sensitivity of the ear of a partially deaf person one may speak more loudly to him, he may bring his ear closer to the source of sound or attempt to capture more of the sound energy by putting his hand behind his ear. These obvious methods are, however, useless when the threshold of the sense of hearing of the person in question lies too high, and moreover they usually have the undesired result that the remarks of those with normal hearing assume an unnatural character. After the invention of the telephone, technology was able to offer a more satisfactory method of increasing the intensity of sound: a combination of a head-phone and a carbon microphone, fed by a dry cell carried in the pocket. This instrument however has often proved disappointing. The increase in the level of intensity is here obtained at the expense of the quality of the sound heard: in order to make the telephone sufficiently sensitive for the very weak microphone currents, use must be made of resonances in the oscillating system, which means that

certain frequencies are favoured and considerable distortion of the sounds taken up by the microphone occurs. In *fig. 1* an example is given of the frequency characteristic of a telephone such as is used in the combination in question. The carbon microphone itself also has an irregular frequency characteristic which adds to the distortion. Due to the distortion, the intelligibility is very much decreased, a fact which is confirmed by the common experience that much more concentration is needed to follow a telephone conversation, especially in a foreign language, than a direct conversation. In addition to this mental fatigue of the deaf person there is also the fact that the ear tends to become overloaded by the peaks in the intensity at the resonance frequencies of the characteristic, which may, especially, for weak ears, be very painful, and is quite undesirable.

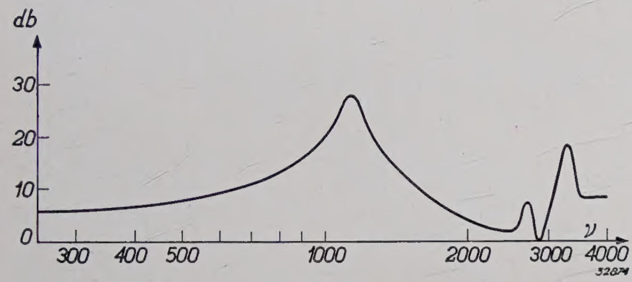


Fig. 1. Frequency characteristic of a telephone which is sufficiently sensitive to be connected directly to a carbon microphone with pocket battery. The great sensitivity is obtained by means of resonance peaks, and thus at the expense of the quality of the sound reproduction. (The curve is drawn according to a characteristic measured by W. West and D. Mc. Millan: J.I.E.E. **75**, 328, 1934, fig. 8).

The application of an amplifier

These difficulties can be avoided when very good quality microphones and telephones are employed. Such instruments are at present available. Their much lower sensitivity, however, which is the inevitable result of the desired flat form of the frequency characteristic, makes the use of an amplifier necessary. Moreover, the use of an amplifier is also advisable because it makes possible other improvements in the apparatus. We shall discuss these improvements in the following on the basis of an apparatus designed and constructed in the Philips laboratory at the suggestion of Dr. Köster, ear specialist in the Hague, for one of his patients. The requirement that the apparatus should be portable was given up, so that it was possible to start from ordinary amplifiers.

The sensitivity of the ear of deaf persons is lower than that of those with normal hearing. The decrease in sensitivity is generally however not the same for all frequencies. The sense of hearing may for example be less acute for low frequencies only, or for high frequencies only. Instead of the normal variation of frequency of the threshold of hearing, which is reproduced in *fig. 2*, a different curve is

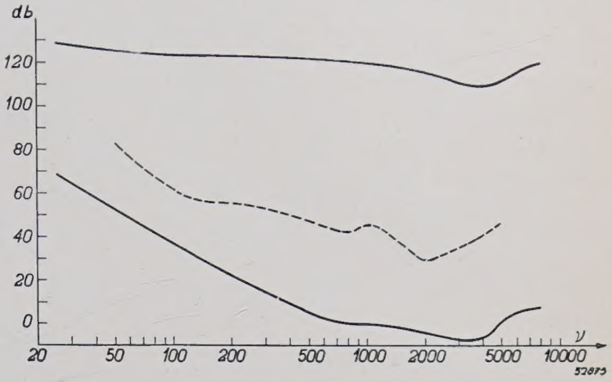


Fig. 2. The auditory range of the normal ear (full lines). The lower line gives, as a function of the frequency in c/s, the minimum intensity in decibels which can be observed (threshold value, the threshold for the frequency 1 000 c/s is put equal to zero decibels). The upper line gives the pain limit. In the case of a deaf person the sensitivity of the ear is decreased for some or all frequencies, *i.e.* the threshold is higher. In one individual case the threshold curve indicated by the broken line was found.

found. The ear specialist measured the difference between the threshold values of the person in question and those of a person with normal hearing. The difference has been plotted above the normal threshold in fig. 2, and the broken line threshold curve was obtained. If it is desired to match the auditory impressions of the deaf person as closely as possible to those of the normal person, it is obvious that the amplification for the different frequencies should correspond to the measured difference in sensitivity. This may be realized in a relatively simple manner, since the frequency characteristic of the amplifier to be used can be given any desired form by suitable connections. The frequency characteristic of the amplifier is reproduced in *fig. 3*.

It must be noted that the patient himself does not always

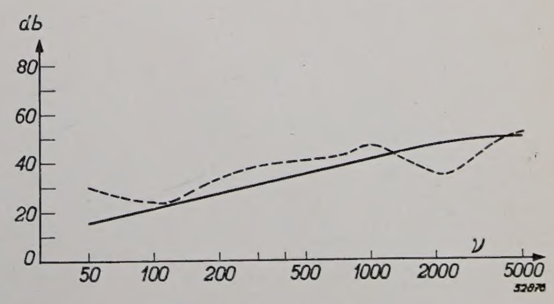


Fig. 3. Decrease in the sensitivity of the ear (broken line) of the deaf person for whom the apparatus described was designed. (The curve refers to the broken threshold curve in fig. 2; the measured difference between the full line curve and the broken line threshold curve is here plotted). The full line curve is the frequency characteristic of the amplifier used. The decrease in sensitivity of hearing is satisfactorily compensated.

accept as an improvement such an adaptation of the amplifier to his individual hearing deficiency. Sometimes this is even felt to be unpleasant. This must probably be ascribed to the fact that the partially deaf person who has for years been compelled to hear without correction has become accustomed to a certain distortion of the sound, and therefore finds "unnatural" the quality of sound which is natural for normal ears. The decision whether in such a case an adaptation is nevertheless desirable in order to accustom the patient to normal sound once more must of course be left to the specialist in charge.

Moreover, there are also cases of deafness where the hearing deficiency at normal intensities differs from that at intensities in the neighbourhood of the threshold value. In such cases it is even more necessary to consult the ear specialist before attempting to use an amplifier.

Due to the narrow margin between the threshold of ear sensitivity and the pain limit in the case of the deaf, it is very important that the amplifier currents fed to the amplifier should not exceed a certain limit. For this purpose an automatic volume control may be introduced, by which the sound intensity to which the ear of the patient is exposed can be limited for example to 20 or 30 dB above the threshold.

Possibility of directional hearing

In the apparatus in question special care has been taken that the deaf person is not robbed of the possibility of directional hearing. Many people are unaware of the practical significance of this possibility, which is based on the simultaneous observation with both ears. It is however easy to convince oneself of the importance of directional hearing by temporarily covering one ear. In a room in which several different conversations are being carried on at the same time it will now be found practically impossible to follow one of them, while under normal circumstances this requires only slight concentration: by directional hearing one is able to concentrate one's attention in a given direction and the stimuli from other directions can be psychologically pushed into the background. This phenomenon plays an important part when there are disturbing noises. In "binaural" hearing only that sound is observed which comes from the direction on which the attention is concentrated. In "monaural" hearing on the other hand disturbing noises from all directions are active at the same time. This is the reason why users of instruments for the deaf so often complain of the "noise": in a combination of for example a microphone worn on the breast and two head-phones connected to it, the sound is received by only one "ear" (the opening of the single microphone). This is also a reason why the greatest possible quiet must be maintained in broadcasting studios, and the reverberation must in such cases be less than normal: the listener receives the sounds, which strike the microphones from all directions in the studio, from only one direction, namely from the opening of the loudspeaker.

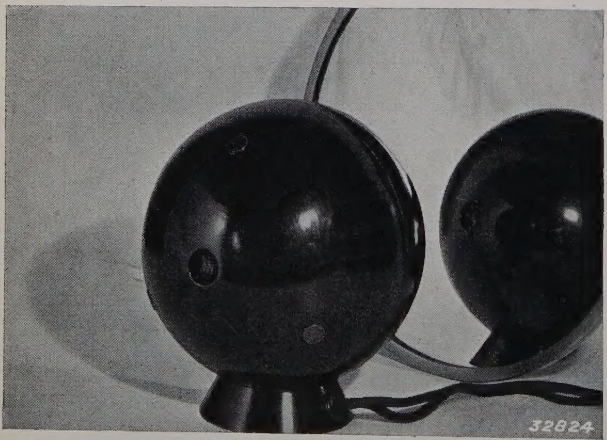


Fig. 4. The sphere used as "artificial head". It has a diameter of about 22 cm. The two microphones are mounted at the extremities of a horizontal diameter. (In order to make visible both microphones the sphere has been placed before a mirror.)

Fig. 5. The model with which the influence of the details of the shape of the head were studied. The microphones are mounted in the ears and feed the head-phones of the user.

The method by which directional hearing can be retained when hearing takes place through microphones is obvious. Two microphones must be used,

Fig. 6. View of the apparatus during use. The artificial head is placed on the table. The two amplifiers are set up under the table.

each of which feeds one telephone *via* a separate amplifier adapted to the ear in question [1]). In order to provide that the intensity and time differences between the sounds caught by the two microphones, which give the sense of direction, shall correspond to those in normal hearing with both ears, the microphones must be mounted on an "artificial head" which causes a distortion of the sound field similar to that caused by the human head. As artificial head it is sufficient to take a sphere which has about the same dimensions as the head, see *fig. 4*. The microphones are mounted on the sphere at the extremities of a horizontal diameter.

All the phenomena of directional hearing cannot be explained by the above-mentioned differences in intensity and time. These differences are for instance the same for two sources of sound one of which stands to the right in front of the listener and one to the right behind him. It is however possible to localize sounds "in front of" and "behind" one even with the eyes closed. It was not unreasonable to suppose that the details of the shape of the head played their part in this phenomenon. We therefore carried out listening tests with a set of microphones in which the head was approximated, not by a sphere, but by an artificial head with more natural detail (*fig. 5*). There was however no appreciable difference with respect to the same observations with the sphere. The distinction between "in front of" and "behind" when visual observation is impossible, seems rather to be obtained by slight movements of the head — a means which is of course lacking in the arrangement for binaural hearing here described [2]). In order to make this possible, the microphone would have to be mounted directly on the headphones, which is at present impossible due to the great weight of the available microphones. The mounting of the microphones on the telephones would moreover also produce the advantage that the user would be able to move his head freely without the occurrence of a contradiction between the acoustically and visually observed directions. When an artificial head is used it must not be placed too far from the user if the acoustic and visual directions are to coincide approximately (*fig. 6*).

[1]) Since in the case in question the hearing deficiency of the left ear had almost the same characteristic as that of the right ear, the same frequency characteristic, shown in fig. 3, was chosen for both amplifiers.

[2]) The following experiment is of interest in this connection. When the artificial head is in a different room from that in which the person using the telephones is situated, the latter localizes a speaker in the correct direction, *i.e.* at that angle at which the speaker is standing with respect to the artificial head, but however always in the direction to the rear. The perception is here apparently influenced by the conviction that a speaker who stands in front of one ought also to be visible.

RECEIVING AERIALS

by J. van SLOOTEN.

621.396.67

A discussion is given of the different factors which must be taken into account in designing a receiving aerial in order to keep the interference level low. A description is then given of the way in which the knowledge of these factors is applied in the design of the "Philistatic" aerial system so that less disturbance from interference is experienced on normal as well as on short waves.

Introduction

A receiving aerial is an electrical conductor or a system of such conductors in which voltages are induced by local electromagnetic fields which may be due to various sources. The function of the receiving set is to amplify only those voltages from the desired transmitter and to convert them into sound. The possibility of this selection is based on the fact the transmitting stations all work on different frequency bands.

If in the aerial undesired voltages are induced (interferences due to electrical apparatus, for example) whose frequencies fall within the frequency range of the transmitter which is being received, then generally speaking interference-free reception is no longer possible even with the best receiving set.

The avoidance of such undesired voltages must therefore be considered as belonging to the function of the aerial. In addition the aerial also of course has the task of capturing the desired signals in adequate intensity.

At the beginning of the development of radio technology when receivers were much less sensitive and transmitters much weaker than at present, the latter function of the aerial was the most important one. At present, however, the sensitivity of aerial and receiver together is almost always great enough to reproduce an interference-free transmitter with the desired intensity. It is now worthwhile therefore to apply measures for increasing the ratio between signal and interference even though this takes place at the expense of the signal intensity itself [1]).

The possibility of choosing between desired signal and interference signal lying in the same frequency band by suitable construction of the aerial is due to the following points of difference which may exist between the two signals:

1) *The direction of propagation of the electromagnetic wave.*

Most aerials receive signals coming from different directions with different intensities. This effect is very pronounced in the case of the loop antenna, which can therefore in certain cases be used to weaken interferences.

2) *The electromagnetic character of the wave.*

It may be stated that, in the neighbourhood of a source of interference, the electric field is caused by the voltages and the magnetic field by the currents present in the source of interference. It therefore depends entirely on the nature of the source of interference whether the electric or the magnetic field is the stronger. At a distance which is large compared with the wave length, however, the nature of the transmitter no longer has any influence on the electromagnetic field; the electric field strength is then induced by the change in the magnetic field and *vice versa*. This phenomenon is expressed in Maxwell's famous equations. Electrical and magnetic fields then have a fixed relation to each other, and when expressed in certain units are numerically equal (the electric field in volts per metre is 30 000 times the magnetic field in oersteds).

The ratio between the intensities of the signals of the source of interference and the transmitter may therefore be quite different for the electrical field strengths than for the magnetic field strengths. In the neighbourhood of a source of interference the electric field is usually the greater; if one then for example makes use of a loop antenna which is mainly sensitive to magnetic fields, the ratio between the intensities of interference and signal will be smaller than when an ordinary T-aerial is used.

3) *The distribution in space of the intensity of the field of the transmitter and of that of the interference.*

The field of the transmitter which is excited at a great distance from the receiver will be

[1]) This may not of course be carried too far, because the useful sensitivity of a receiver is limited by the noise which is excited in the first amplifier stages. In the case of an aerial signal stronger than about 1 millivolt the influence of this noise is as a rule unnoticeable. See in this connection Philips techn. Rev. 3, 189, 1938.

stronger out of doors than indoors. The interference signals, which are usually present on the electrical conductors of the light mains, will, on the contrary, be stronger indoors than out of doors. By constructing the aerial in such a way that a certain part of it, in our case the part inside the house, is not sensitive, the ratio of intensities of interfering signal to receiving signal can be reduced. On this effect is based the action of the aerial with shielded connections, which is called "shielded aerial" for the sake of brevity. We shall discuss this in the following.

The shielded aerial

We shall examine in this chapter how a nearby source is received by an aerial with and without shielded leading in wire.

In *fig. 1a* is shown an aerial consisting of a vertical and a horizontal wire. The source of interference is represented as a sphere S on which there is an interference voltage. The interferences are transferred from the sphere S to the aerial capacitatively. In the figure the divided capacity between the source of interference and the aerial is represented by the four capacities C_1—C_4. The capacities C_3 and C_4 toward the vertical wire close by will be the largest.

If we now place an earthed shield around the vertical wire, as indicated in fig. 1*b*, the capacities C_3 and C_4 will become ineffective, since the course of the lines of force between the shielded wire and the source of interference is intercepted by the earthed covering. As a result the greatest part of the interference will disappear.

Let us now examine the influence of the shielding on the signal voltage which is excited in the aerial

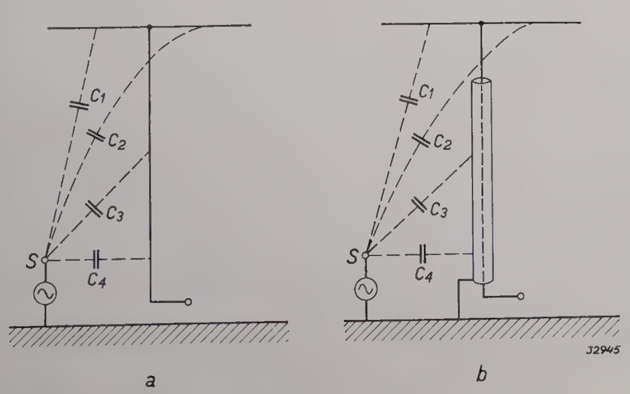


Fig. 1. The voltage of a source of interference S in partially transferred to the aerial by means of the divided capacity which is represented by the condensers C_1 to C_4. In case *a* of the non-shielded aerial the capacities C_3 and C_4 toward the supply line are the most important ones. In the case *b* of the shielded aerial these capacities become ineffective, so that the interference can be considerably reduced.

by a distant transmitter. For the sake of simplicity we shall do this somewhat roughly.

The electrical component F of the field (*fig. 2a*) has a vertical direction and excites in the aerial a voltage equal to this field strength multiplied by the height of the aerial. The voltage excited is therefore equal to the electrical potential at the height of the horizontal section.

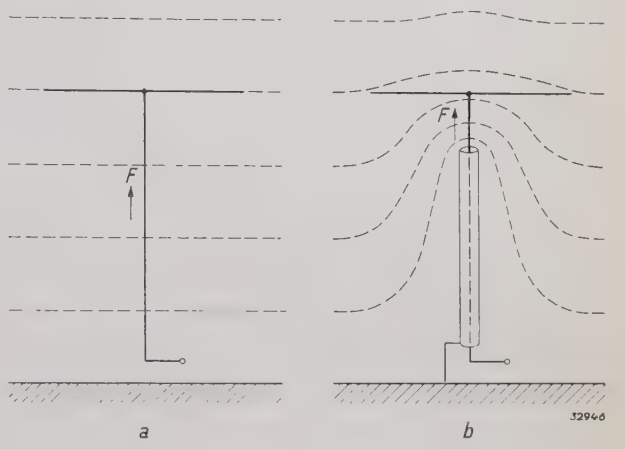


Fig. 2. Equipotential surfaces of a transmitter field: *a*) with a non-shielded aerial, *b*) with a shielded aerial. Although the equipotential surfaces are very severely distorted locally by the shielding, the potential at the position of the horizontal aerial wire has retained pratically its original value, which means that the signal is only slightly weakened. The action of the aerial wire itself on the form of the equipotential surfaces has been neglected in the drawing.

If we now apply shielding (fig. 2*b*), the field is locally distorted. The earth potential is raised and the potential drop on the field strength is very much increased at the upper edge of the shield. If we go still higher we see that the disturbance of the potential field decreases rapidly so that at the position of the horizontal wire of the aerial the potential is again about the same as when the earthed shielding is absent. (see fig. 2*b*). If the free part of the aerial is not too small with respect to the shielded part, we may therefore state that the induced voltage is only slightly decreased by the shielding.

Summing up, therefore, we may say that due to shielding the voltages coming from nearby sources of interference are considerably weakened, while the voltages from distant broadcasting transmitters experience only a slight attenuation.

Until now we have considered only the voltage which is induced in the aerial. If we now examine what part of this voltage acts across the input terminals of the receiving set, we find that an additional weakening occurs due to the shielding.

In order to explain this more fully an equivalent circuit diagram is given in *fig. 3* for an aerial with a receiver having an input impedance of z. If E_a

is the voltage excited in the aerial, a current will flow through the receiving set which, in the case of a non-shielded aerial (fig. 3a) is given by:

$$I = \frac{E_a}{z + 1/j\,\omega\,C_a} \quad \cdots \cdots \quad (1)$$

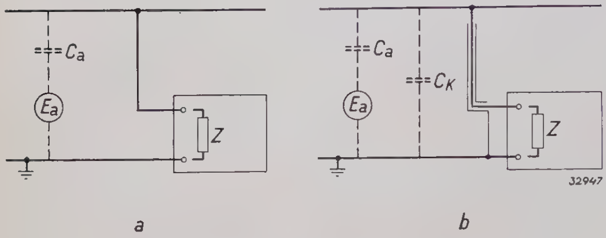


Fig. 3. Equivalent circuit: a) of a non-shielded aerial, b) of a shielded aerial. E_a aerial voltage, C_a aerial capacity, z input impedance of the receiving set, C_k capacity of the aerial supply line toward the earthed mantel of the shielding.

It is hereby assumed that the capacity C_a is concentrated in the horizontal section of the aerial. If that is not the case, equation (1) must be replaced by a more complicated expression. This is, however, unnecessary for our purpose. The voltage on the impedance z is equal to the current I multiplied by z and thus given by:

$$E = \frac{E_a\,z}{z + 1/j\,\omega\,C_a} = \frac{E_a}{1 + 1/j\,\omega\,z\,C_a} \quad \cdots \quad (2)$$

Therefore when the impedance z is large with respect to that of the aerial capacity, the voltage on the impedance z remains practically equal to E_a.

If we now replace the vertical wire by a concentric cable with an earthed mantel the internal capacity of this cable is connected in parallel with the impedance z (see fig. 3b). If we consider z to be very large with respect to the impedance of the aerial capacity, and if we call the internal capacity of the cable C_k, the voltage over the input terminals of the receiving set becomes:

$$E_k = \frac{E_a\,C_a}{C_k + C_a} \quad \cdots \cdots \quad (3)$$

When C_k is larger than C_a, which is usually the case, considerable attenuation of the aerial signal occurs. The remaining interferences are in this case weakened to about the same extent as the desired signal, so that the ratio of signal to interference is not altered by the presence of C_k.

In order to keep this undesired attenuation small it is necessary to make C_k small and therefore the cable lead as short as possible and to use for this purpose cable with as low internal capacity per unit of length as possible, *i.e.* cable with a very thin core. The decrease in cable capacity hereby attainable is however limited, because one cannot use wire thinner than about 0.25 mm in connection with its mechanical strength. If for reasons of practical or aesthetic nature a small aerial is used, then, in spite of the use of a cable of low capacity, the signal may be weakened more than is permissible.

In such cases considerable improvement can be obtained by including a transformer between the free portion of the aerial and the cable lead. The primary of this transformer is connected between the aerial and the earthed mantle of the cable; the secondary between the mantle of the cable and the lead wire. By means of this transformer the aerial is as it were "adapted" to the loading by the undesired cable capacity. The fundamental scheme of the transformer is given in *fig. 4*; a shows the connection and b the equivalent circuit.

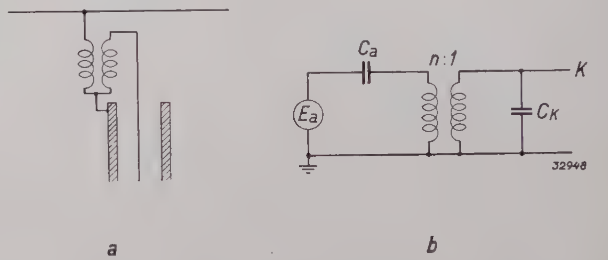


Fig. 4. a) Connections, b) equivalent circuit of an aerial with a transformer connected between the free end and the shielded supply wire. By transforming the aerial voltage downward, the harmful action of the capacity between supply wire and shielding can be reduced.

If the transformer attenuates the voltage which is supplied by the aerial to the core of the cable in the ratio n : 1, we find for the voltage on the terminal K:

$$E_k = \frac{1}{n}\,E_a\,\frac{C_a}{C_a + \dfrac{C_k}{n^2}} \quad \cdots \cdots \quad (4)$$

This expression reaches a maximum when we choose for the transformation ratio:

$$n = \sqrt{\frac{C_k}{C_a}}$$

and then

$$E_k = \frac{E_a}{2}\sqrt{\frac{C_a}{C_k}} \quad \cdots \cdots \quad (5)$$

When equations (3) and (5) are compared, it is found that the introduction of the transformer in the case where $C_k \gg C_a$, can produce considerable gain.

In the foregoing consideration an ideal transformer is assumed, *i.e.* a transformer without leakage and with very high values of primary and secondary

self-induction. In practice leakage is present, and the practical values of these selfinductions, which form resonance circuits with the capacities C_a and C_k must be considered. By giving the transformer suitable dimensions, a more satisfactory result can be obtained with the help of this resonance in the wave length range with which we are concerned in practice than is indicated by equation (5).

The "Philistatic" aerial systems

The "Philistatic" aerial sytems 7 323 and 7 314 have been developed with the foregoing considerations in view, and a brief description is therefore sufficient.

In the system 7 323 the aerial proper consists of two straight wires in V form, connected in parallel. A large capacity with small dimensions of the aerial is hereby obtained. The wires are fastened to an insulator which screws together, in which the intermediate transformer is housed and to which the beginning of the low capacity lead cable is also fastened.

The length of the cable may be up to about 60 m, and as many as six receiving sets may be connected to it.

In the system 7 314, whose action is entirely analogous the aerial proper consists of a vertical rod $3^1/_2$ m long. This rod is fastened, *via* an insulating intermediate section which includes the adapting transformer, to a supporting rod which is fastened for instance to a chimney. *Fig. 5* shows such a system installed. Both of these systems are suitable for the reception of all wave lengths between 10 m and 2 000 m, although in their design primary attention was paid to the best possible reception of medium and long waves (200—2 000 m).

There are in addition two other "Philistatic" aerial systems in which primary attention has been given to the reception of short waves (15—50 m).

The action of these systems (types 7 320 and 7 313) is very different from that of the previously described system. Their construction is indicated diagrammatically in *fig. 6*. The aerial consists of two horizontal sections 7 m long; it is therefore a so-called dipole. By a "transmission line" consisting of the wires *a* and *b*, this dipole is connected with the receiving set.

It is found that, thanks to the symmetry of the arrangement, the transmission line is insensitive to interferences so that it need not be shielded. Since the two wires of the transmission line run close to each other, any source of interference will have the same capacity toward both conductors. Consequently currents will occur in both conductors which are equal in magnitude and phase and flow off to earth *via* the coils *1* and *2* respectively, and the circuit elements *L*, *R* and *C* which we think substituted by a short-circuit. The receiving set is connected to the secondary coil *3* of the trans-

Fig. 5. A "Philistatic" aerial, type 7 314 mounted on a chimney. From the upperside to the bottom: the aerial rod; the transformer; a hollow tube, fastened with two isolators to the chimnay, on which the transformer is mounted; the shielded cable, which is conducted vertically downward through the hollow tube.

former. In this coil inverse voltages are induced through the coils *1* and *2*, which voltages exactly neutralize each other in the case in question, so that no interference signal occurs.

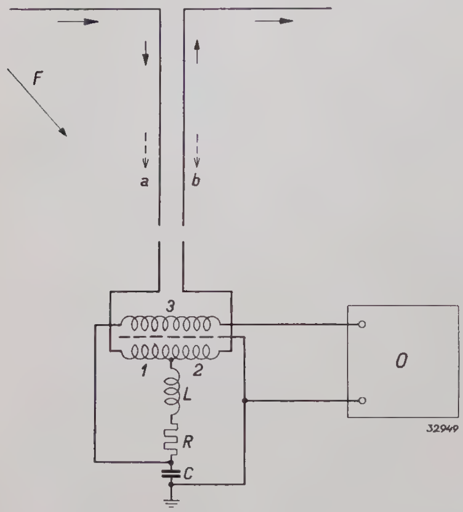


Fig. 6. A "Philistatic" aerial system which is especially suitable for short waves. On short waves the aerial acts as a dipole and the signal causes voltage differences between the wires *a* and *b*. An interference would excite no voltage between the two wires themselves, but between the wires and earth, the input signal produced in this way is however very much reduced by the choke *L* and the capactiy *C*. On long waves this *L*-*C* circuit is less effective, and the whole acts as an ordinary T-aerial.

If the electric field of the transmitter were exactly perpendicular to the arms of the dipole it would, as well as the disturber have no effect on the receiving set. Generally, however, the electric-force (*F* in fig. 6) has a component in the direction of the dipole and in the given case this component will cause a current in the arms of the dipole in the direction of the arrows. This current flows through the two wires of the transmission line in opposite directions. It flows through the primary winding of the transformer (coils *1* and *2*) and thereby induces a reception signal in the secondary winding (*3*).

This design is quite correct for short waves, but with wavelengths above 200 m it works less favourably than a normal T aerial. In the design of the "Philistatic" dipole aerials care therefore was taken that they should work on long wave lengths as T aerials. For this purpose the middle tap of the transformer has been earthed *via* the condenser *C*. The voltage on the condenser increases with the wavelength and at long wavelengths it works as the reception signal.

The described change has the consequence that the aerial is not free from disturbances on short waves. The disturbing currents will induce at the condenser a small voltage, which quite as the reception signal on long waves is passed to the receiving set. For the elimination of this disturbing current a choking coil (self-induction *L*, resistance *R*) has been inserted in the middle tap. To prevent that this will become short circuited with high frequencies by the capacity between the primary and secondary windings of the transformer these windings are separated electrostatically. In this manner — as far as are short waves concerned — a good reception is obtained.

If the removal of interference is also desired on broadcasting waves, the transmission line must be shielded. This has been done in system 7 313. In system 7 320 shielding is not present, and the removal of interference is therefore only valid for short waves.

AN APPARATUS FOR ARTIFICIAL RESPIRATION ("IRON LUNG")

by J. B. ANINGA and G. C. E. BURGER. 614.888.5

In the case of a disturbance in the functioning of the respiratory muscles, for instance in cases of suspended animation or paralysis, artificial respiration must be applied. This is made possible even when the condition is of long duration by an apparatus which causes a periodic expansion of the lungs ("iron lung"). On the principle of Drinker the patient's body is enclosed in an air-tight chamber in which alternations of pressure are generated, while the patient's head remains outside the air-tight chamber. In the apparatus on this principle developed by Philips the chamber is made so large that there is space for the doctor or nurse in addition to the patient, for the purpose of carrying out the operations necessary for the treatment. The way in which the alternations of pressure are brought about in the fairly large chamber (volume 1.5 m^3) is described. The driving mechanism is balanced in such a way that upon any interruption of the current from the mains which supply the motor, the apparatus can easily be operated for many hours by hand.

The problem of resuscitation by artificial respiration in cases where the normal respiratory movements have ceased is an old one. Such cases of apparent death, where artificial respiration is indicated, occur especially in the case of victims of drowning or electrical shock or in cases of poisoning by carbon monoxide, etc. The methods of artificial respiration which are usually applied are based on attempts to cause an expansion of the thoracic cavity (inspiration) by movements with the arms of the patient, which by means of the upper arm muscles attached to the chest are able to exert a pulling force on the pectoral wall. Another method is to attempt by direct pressure on the chest to press the air out of the lungs and to allow them to suck in air by means of the elasticity of the pectoral wall. All these methods are fairly primitive, they require great exertion on the part of the person applying them, and they are practically only suitable for use during a few hours. In many of the above-mentioned cases the latter is no objection since the purpose is to remove a condition which is of short duration only. There are, however, also cases where the condition of disturbed natural respiration may last for weeks or months. The most familiar example is the paralysis of the respiratory muscles which may occur as a result of epidemic infantile paralysis. With such cases in view attempts were made to construct an automatically working apparatus which can assume the functions of the respiratory muscles for any length of time desired. With the help of such an apparatus it is in the above-mentioned cases of infantile paralysis not only possible to keep the patient alive, but often to effect a cure. It often happens that the initially occurring disorder is very extended, and that for instance the muscles of arm, leg and respiration are paralyzed, while in the course of weeks a recovery of function occurs due to cure of the inflammation process in the central nervous system which had caused the paralysis.

Mechanization of artificial respiration

Among the different methods for the mechanization of artificial respiration that of Drinker [1]) has proved the most satisfactory. The body of the patient is introduced into an air-tight chamber, while his head remains outside. In this chamber a periodic alternation of pressure is caused. Since the lungs, by way of the mouth, remain in connection with air at normal pressure outside the air-tight space, a movement of inhalation takes place upon decrease of the pressure on the chest and abdominal wall, while upon recovery of the normal pressure or the exertion of extra pressure on the chest, an exhalation movement is carried out.

In principle, the air-tight chamber in which the body of the patient is enclosed, needs only to be large enough for the patient's body. In the first instance it would seem advisable not to make the chamber any larger than necessary since the required alternation of pressure is easier to bring about in a small chamber than in a large one. If, however, the body of the patient is enclosed in a narrow box (as was done in the first apparatus built on the Drinker principle), there are very undesired consequences in connection with the care of the patient. It is obvious that the treatment requires other things besides artificial respiration. For all kinds of daily occurrences such as care of the skin, massage and exercise of paralyzed limbs, the patient must be removed from the apparatus. When this is done artificial respiration ceases, and the patient begins to suffocate. Attempts have been made to

[1]) In the choice of the method to be used, we were advised by Prof. Dr. A. K. M. Noyons of Utrecht.

find a solution for this difficulty by allowing the patient to breathe in a certain amount of oxygen so that the lungs will have a reserve available. In spite of these precautions it is still found necessary to let the "iron lung" resume its function as quickly as possible. It is obvious that this circumstance is very unpleasant and even terrifying for the patient, and requires a high standard of skill of the personnel in charge. Serious doubt may even be felt whether in this way adequate care can be given, especially since it is a question of careful nursing in many cases of infantile paralysis which makes it possible to save the patient.

It was this consideration which led in the construction of the Philips apparatus for artificial respiration to the decision to deviate from the ordinary design. The chamber into which the patient's body is introduced is made so large (see *fig. 1*) that the doctor or nurse can take his place in the chamber beside the patient. Artificial respiration is now only interrupted for a few seconds when some treatment or other is necessary, namely only long enough for the door of the chamber to be opened for the entry of the one giving the treatment.

Driving power of the "iron lung"

The most important problem in the construction of the "iron lung" was the excitation of the required alternations of pressure in the chamber. This is accomplished by periodically increasing and decreasing the volume of a container (air bellows) connected with the chamber. The principle of this process is shown in *fig. 2*, while *fig. 3* is a photograph of the driving mechanism. In order to be able to adapt the magnitude of the pressure differences, as well as the rhythm in which they occur, to the age and condition of the

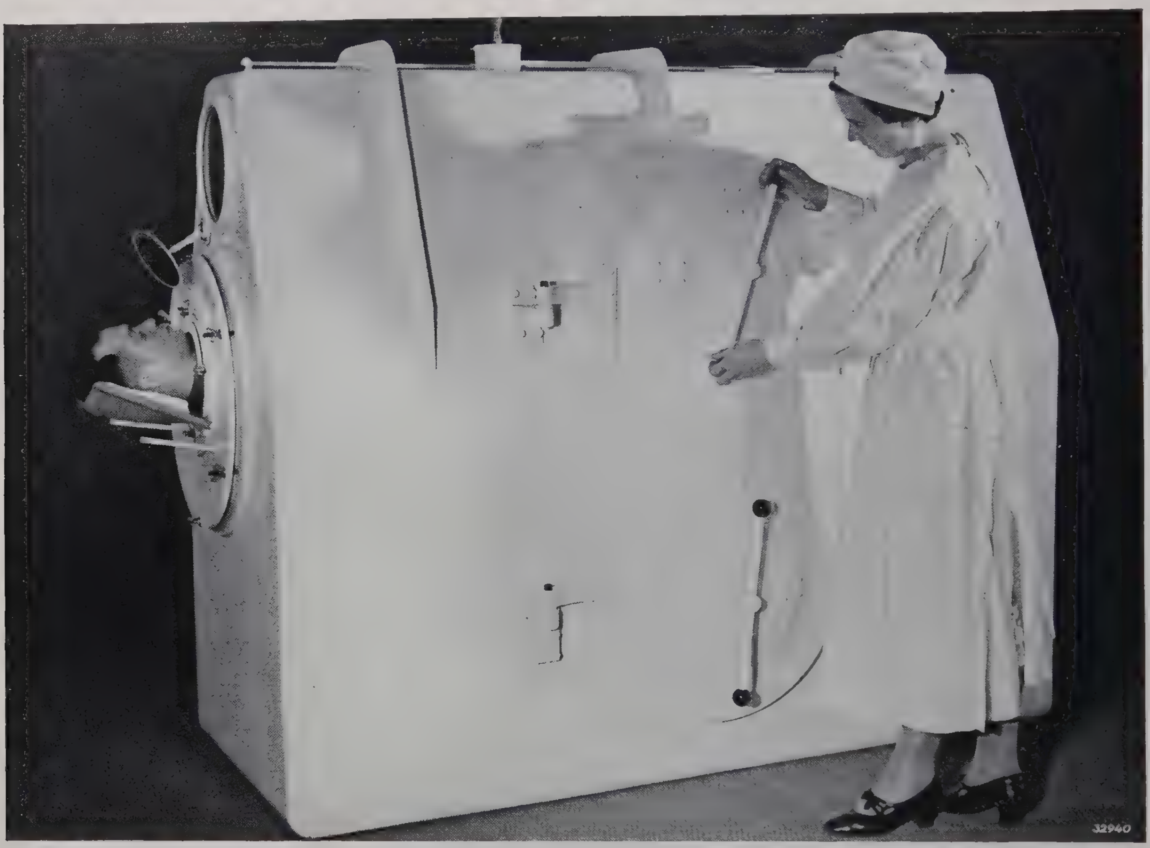


Fig. 1. The "iron lung" in action.

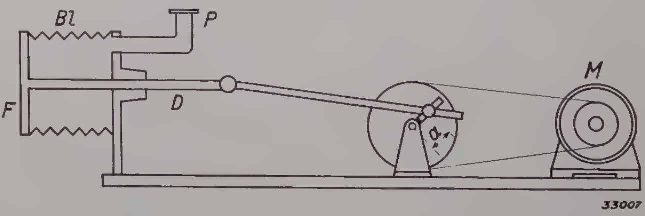


Fig. 2. Diagram showing the principle of the mechanism for generating the pressure alternations in the "iron lung". The bellows *Bl* are connected with the chamber *via* the tube *P*. The rear flange *F* of the bellows is moved back and forth by the driving rod *D* which is moved *via* a lever by the motor *M*. The arm *a* is adjustable in length so that the stroke of the bellows can be regulated.

patient, the length of the arm a (and thus the stroke of the bellows) can be varied, and the shaft is driven *via* a pulley with five sheaves of different diameters which permits adjustment at different rates of breathing.

The required dimensions of the bellows are calculated in the following way. The difference Δp between the highest pressure p_1 and the lowest presure p_2 in the chamber must amount to 0.03 atmosphere in the most extreme case. When we assume that the pressure alternations take place isothermally in the chamber [2]), the product of pressure times volume is constant. Therefore if v_1 is the volume of the chamber and Δv the increase of volume due to expansion of the bellows, the following is true:

$$p_1 v_1 = (p_1 - \Delta p)\,(v_1 + \Delta v)$$

and by approximation

$$\Delta v = \frac{v_1}{p_1}\,\Delta p \quad \ldots\ldots \quad (1)$$

In our case $v_1 = 1.5$ m³ and $p_1 = 1$ atmosphere approximately, so that one finds with $\Delta p_{\mathrm{max}} = 0.03$ atmospheres

$$\Delta v_{\mathrm{max}} = 45 \text{ litres.}$$

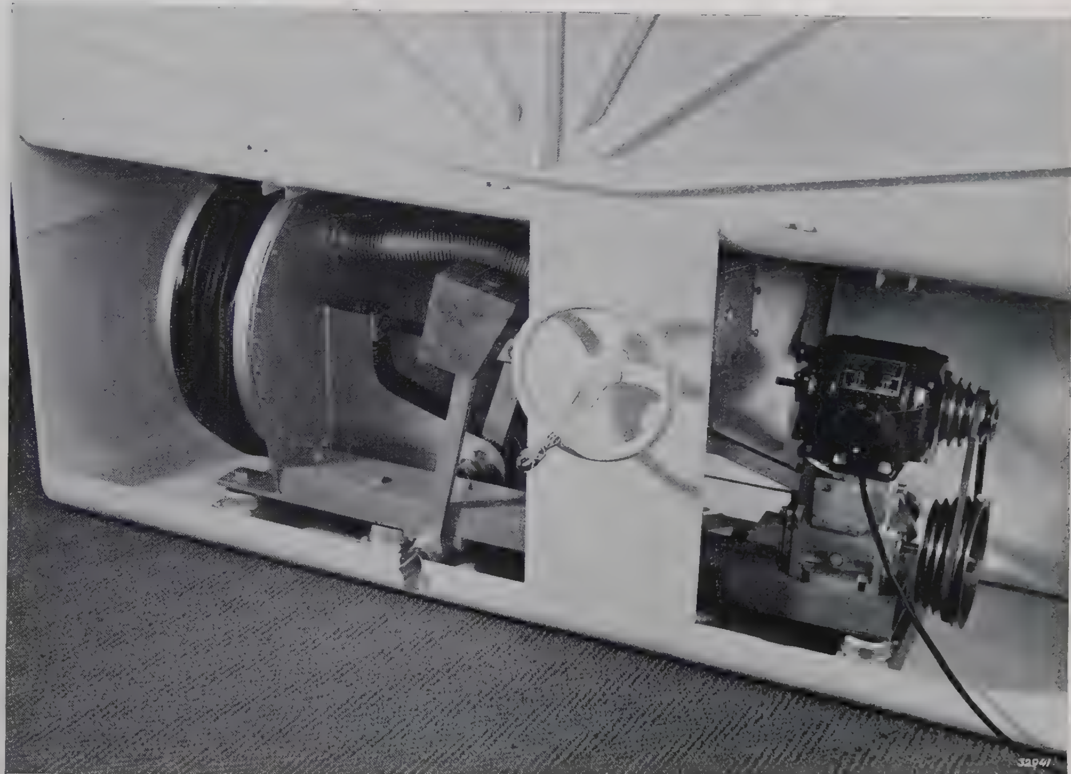


Fig. 3. The mechanism of the "iron lung". On the left the chrome leather bellows, whose expansion causes a decrease in pressure in the chamber. On the right hand the motor which moves the driving rod of the bellows *via* a pulley with five sheaves of different sizes, a worm drive and a lever. By means of the fivefold pulley the breathing rate can be adjusted.

This volume of air must be added and removed from the chamber at each respiration. The cross section area of the bellows is about 1 600 cm²; the movable flange of the bellows must therefore be able to be moved a distance $s = \Delta v / q = 28$ cm back and forth.

Upon expansion of the bellows considerable work must be done in opposing the external atmospheric pressure: at the greatest expansion of the bellows, when the chamber is at a decreased pressure of 0.03 atmosphere, the atmosphere presses against the movable flange with a force of $1\,600 \times 0.03 \times 1.033 = 50$ kg. The energy supplied during the expansion of the bellows can, however, be recovered when the external atmospheric pressure is

[2]) Actually, at the frequencies of respiration (15 to 30 per minute), a temperature equilibrium between the volumes inside and outside the chamber will not continually be established. With perfect heat insulation, the pressure variations would take place adiabatically, and $pv^{\varkappa}$ instead of pv would be constant with $\varkappa = 1.4$. In practice a polytrope with $1 < \varkappa < 1.4$ will best approximate the truth. One then in any case obtains a certain change of pressure with a smaller volume change than in the case of an isothermal variation. The capacity of the bellows, which is calculated in the following, is therefore larger than is theoretically necessary. The reserve, which is available in this way is of practical advantage since the pressure variations are decreased by different leaks in the chamber which will be discussed.

allowed to do work during the contraction of the bellows, for instance by causing it to raise a weight which produces energy again as the bellows expand. In this way it is possible to use a low-powered electromotor (1/4 h.p. in our case). It is, however, of greater importance that this method of balancing makes it possible to work the bellows by hand without appreciable exertion. This latter factor is essential, since upon any disturbance in the electric mains which feed the motor, artificial respiration must not stop, and the "iron lung" must be able to be kept in action for several hours by a nurse.

The method of balancing the external pressure will be examined in more detail. For the sake of comparison one may recall the way in which a lift is balanced; the lift is coupled with an equal counter weight which moves the same distance downward as the lift moves upward. In the ideal case the couples which act on the axis of the cable drum are in equilibrium at every moment, so that the motive force needs only be enough to overcome the frictional and mass forces. In the "iron lung" mechanism also the aim will be to provide that at every position of the bellows the air pressure is kept in exact equilibrium. In this case, however, in contrast to the example of the lift, the force to be balanced is not constant during the motion of the bellows. With the help of equation (1) one finds for the force $q \times \Delta p$ on the movable flange of the bellows

$$q \cdot \Delta p = q \cdot \frac{p_1}{v_1} \Delta v = \frac{q^2 p_1}{v_1} \cdot x, \quad . \quad . \quad (2)$$

where x represents the displacement of the flange. The mechanism shown in *fig. 4* serves to balance this force. The driving rod D of the bellows is coupled with the shaft A *via* a sliding block B and a slotted bar K. By a gear transmission in the ratio $n : 1$ the shaft C is coupled with A, and to C is fastened a lever H with the variable length h

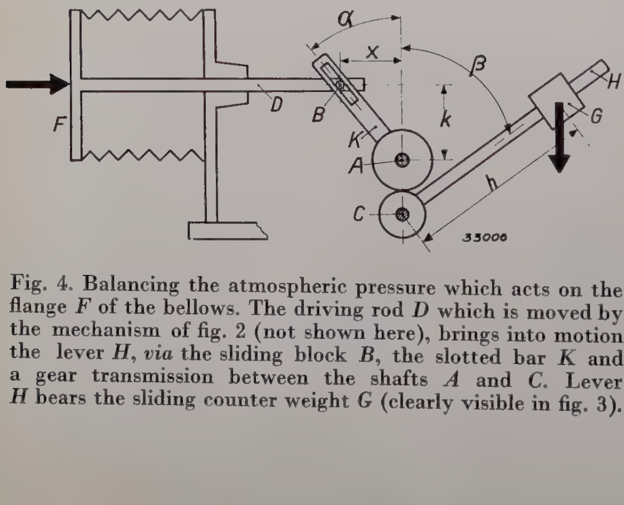


Fig. 4. Balancing the atmospheric pressure which acts on the flange F of the bellows. The driving rod D which is moved by the mechanism of fig. 2 (not shown here), brings into motion the lever H, *via* the sliding block B, the slotted bar K and a gear transmission between the shafts A and C. Lever H bears the sliding counter weight G (clearly visible in fig. 3).

and a weight G. At the initial position of the bellows when the same pressure holds inside and outside the chamber, the lever H stands vertical and the weight G is therefore at its highest position, while upon expansion of the bellows the weight G turns toward a lower position.

It is easy to calculate to what degree the ideal of equilibrium at every moment is approached by this mechanism. We must consider the couples M_L and M_G which are exerted by the air pressure and the weight G respectively on the shaft A. It follows from equation (2) that:

$$M_L = \frac{q^2 p_1}{v_1} \cdot x, \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where k is the perpendicular distance between the driving rod D and the shaft A (in the case of an adiabatic pressure alternation M_L is simply multiplied by a factor $\varkappa = 1.4$). When we call the angles α and β through which the slotted bar K and the lever H respectively are turned, then

$$M_G = n \cdot G \cdot h \cdot \sin \beta,$$

and when we take into account the relations:

$$\beta = n \cdot \alpha,$$

$$\mathrm{tg}\, \alpha = \frac{x}{k},$$

it follows that:

$$M_G = n\, G\, h\, \sin \left[n\, \mathrm{tg}^{-1} \frac{x}{k} \right] \quad . \quad . \quad . \quad (4)$$

Table I

q	=	1 590 cm²
p_1	=	1 atmosphere = 1.033 kg/cm²
v_1	=	1.5 m³
k	=	22 cm
n	=	1.5
G	=	20 kg
h	=	varies between 20 and 40 cm

In *table I* the data necessary for the calculation will be found. In *fig. 5* the couples M_L and M_G calculated from (3) and (4) are plotted as functions of x for different values of the parameter h. It may be seen that by a suitable choice of h, the position of the moving weight G, the curve M_G can be made to coincide almost exactly with the curve M_L at small values of x. Only in the most extreme positions of the bellows ($x > 20$ cm) does the shape of the two curves remain very different. In practice, however, no greater stroke s of the bellows is required than about 18 cm (corresponding to a difference in pressure of 0.2 atmospheres, with isothermal variation). The optimum position of the weight G depends upon the

necessary stroke. At $s = 18$ cm, for example, h would have to be taken equal to about 23 cm in the case of isothermal variations. The personnel in charge can determine the optimum position of the weight most easily by experiment.

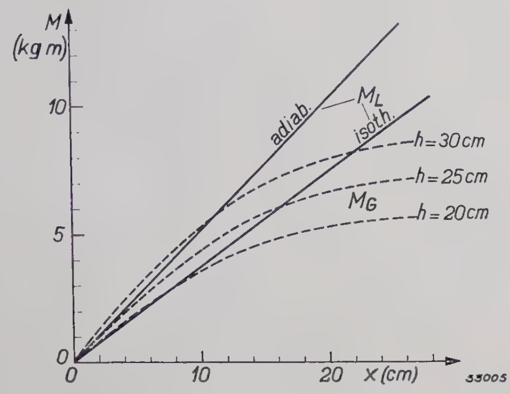


Fig. 5. The couples M_L and M_G exerted by the air pressure and the counter weight respectively on the shaft A should be exactly equal for each position x of the bellows in an ideal case. The actual curves of M_L and M_G coincide fairly well when the stroke of the bellows is not too large (when, for instance, $x < 18$ cm), and when for the parameter h (position of the sliding weight G in fig. 4) a suitable value is chosen which is adapted to the stroke. M_L is here shown for both adiabatic and isothermal pressure variations. The actual curve will lie between these two.

It must still be noted that respiration with the "iron lung" can take place in different ways: the pressure in the chamber can be alternated between normal pressure and a lower pressure; or it may be made alternately higher and lower than normal [3]). In the first case force is only used for the inspiration, in the second case for in- and exspiration. In the foregoing and in fig. 5 we have assumed the first case. If the physician chooses the second method, the lever H bearing the counter weigth Q is set at a different angle, so that it becomes vertical when the bellows are in the middle of the full stroke. The curves for the balancing in fig. 5 are then prolonged symmetrically for negative values of x.

For working the apparatus by hand a long lever

[3]) In the first case, where the pressure in the chamber must never be higher than the external pressure, this is guaranteed in a simple way by means of a valve on the top of the chamber which allows air to escape when there is an excess pressure in the chamber. In working according to the second method this valve is fixed.

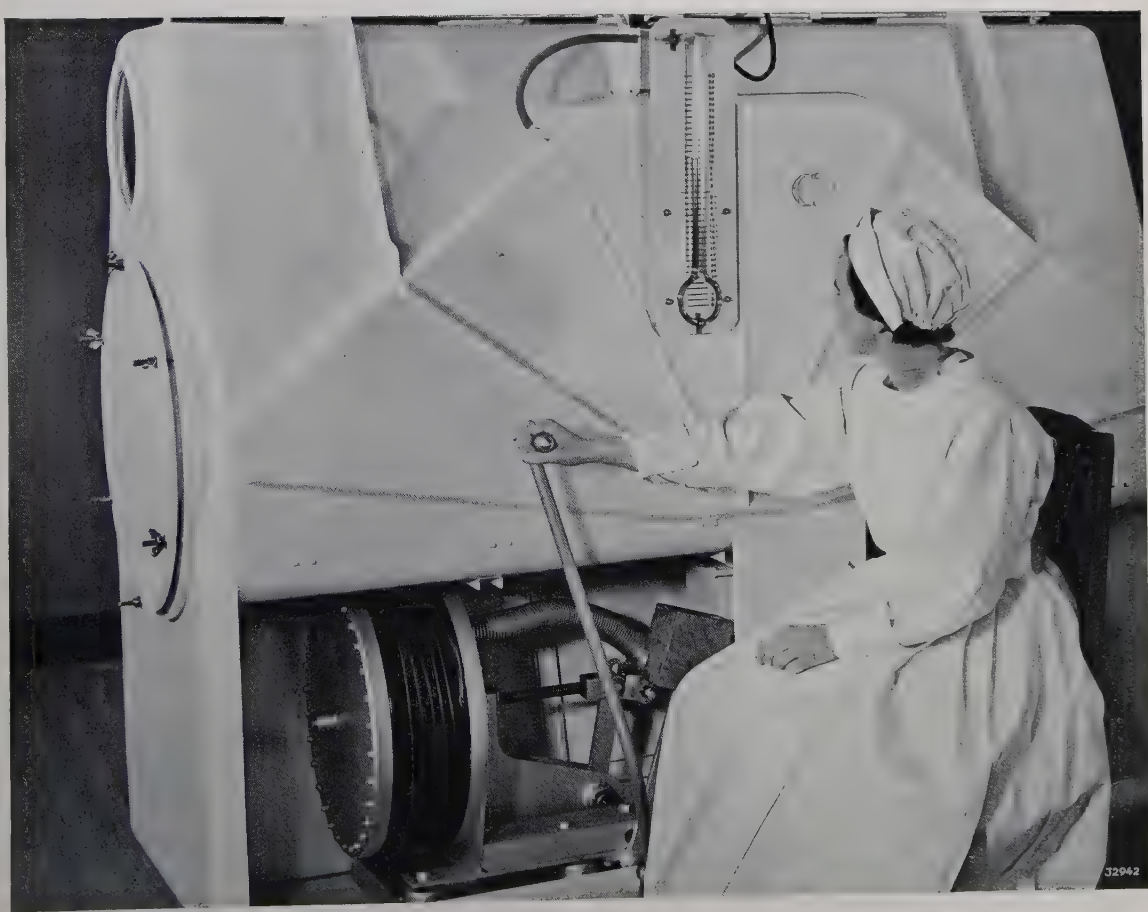


Fig. 6. The "iron lung" worked by hand. The person moving the handle can read off on the manometer the magnitude of the pressure alternations, and regulate the motion accordingly.

with a handle is attached to the end of shaft *C*, see *fig. 6*. The person moving the handle can read off on a manometer the magnitude of the pressure changes, and regulate the motion accordingly.

Further details of the construction

The chamber must be strongly built since it must resist large forces (several tons) during the pressure changes. It is welded from 1.5 mm steel sheet. Steel reinforcements have been entirely avoided on the inside in order to have smooth walls which can easily be cleaned. The chamber is mounted on four rubber wheels and is thus easily moved about. It is so narrow that it can pass through a door 90 cm wide. The bellows are connected by means of a flexible tube with the chamber, and together with the driving mechanism rest upon pieces of rubber so that any vibrations of the mechanical parts are not transmitted to the chamber. The body of the patient is introduced through an opening into the chamber. This opening is then closed with a cover (see fig. 1). Instead of one adult patient, two children can be treated at once in the apparatus. For this purpose two beds are placed end to end in the chamber and there is an opening for the patient's head at both ends. In the treatment of the patients great value is attached to the possibility of placing them in the socalled von Trendelenburg position, *i.e.* sloping, with the head low. A better drainage of saliva is hereby guaranteed and choking prevented and thus the occurrence of complicating inflammations of the lungs. The two beds can therefore be given a slope of 20° by means of the hand wheel visible in fig. 3. For an adult the two beds are coupled together to give a single bed which can be given a slope of 15°.

It is obvious that the chamber must be air-tight in order to obtain the necessary pressure alternations. Since the patient's head must remain outside the chamber, an air-tight seal is necessary around his neck. This is achieved by means of a collar whose construction is shown in *fig. 7*. The two thin rubber rings *1* have a slightly smaller diameter than the neck, and the edge of one is stretched upward and that of the other downward along the neck so that the seal is satisfactory for lowered as well as for excess pressure, without any discomfort to the patient. The leather supporting rings *2* are provided with four radial slide fasteners which are opened for the easy insertion of the head into the collar. The collar is not fixed in a permanent position in the cover of the chamber but it can be adjusted in any desired position by means of screws which slide in grooves. This may clearly be seen in *fig. 8*. The patient can therefore for example be laid on his side without it being necessary to turn his neck in the rubber rings.

The door which permits entry into the chamber is also sealed with rubber. Leaving or entering the

Fig. 7. The patient's head rests on a cushion supported by two iron bolts. When the patient's bed is made to slope (von Trendelenburg position) the cushion is suspended between two lower bolts. The nurse inside the chamber can see the patient's face through a window. Above the patient's head is a turning mirror in order to give the convalescent patient more contact with the outside world.

chamber costs the patient only two to three respirations. The nurse experiences no discomfort at all from the alternations of pressure in the chamber, the only sensation is a feeling of slight "fluttering" of the ear drums, which is decreased by swallowing, and which can be combatted if desired by cotton in the ears.

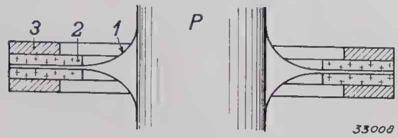


Fig. 8. Construction of the collar for sealing off the air-tight chamber around the neck of the patient. *P* neck of the patient, *1* thin rubber rings, *2* chrome leather supporting rings with slide fasteners, *3* metal rings for clamping, with which the whole arrangement is fastened so that it can be rotated in the cover of the chamber which opens to the side.

In one place a "leak" has expressly been introduced into the chamber wall, namely a small circular opening which can be more or less closed with a slide (visible in fig. 6 above the nurse's head). Fine regulation of the pressure alternations is hereby made possible, while by the successive escaping and sucking in of a small quantity of air, ventilation of the chamber is also obtained.

In order to control the working of the apparatus a signal lamp (visible on fig. 1) has been installed above the chamber, which is switched on and off in the rhythm of the respiration by a membrane moving under the influence of the pressure variations.

Through a window in the chamber (see fig. 8) the nurse can see the patient's face while she is attending to his needs in the chamber. In order to give the convalescent patient more contact with his environment, a mirror is mounted above his head, which is fastened with a ball and socket joint in the wall of the chamber and which can be turned in all directions by the patient's hands inside the chamber.

The effect of the "iron lung" can be made directly visible by recording the patient's breathing. *Fig. 9* is an example of such a record. The force of the "iron lung" is so great that it is practically impossible even for a healthy person to breath in opposition to the "iron lung" by the use of his respiratory muscles. This is clearly shown in fig. 9.

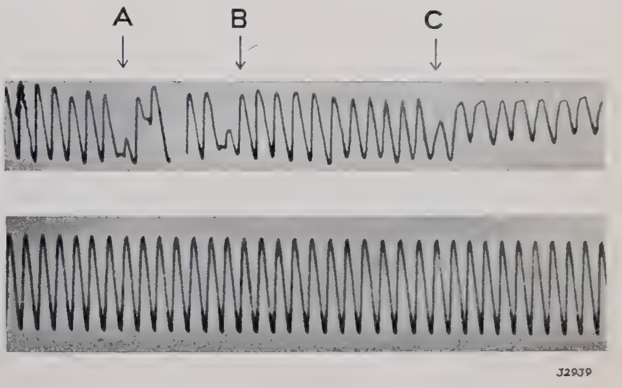


Fig. 9. Record of breathing in the "iron lung". The lower strip gives the strokes of the "iron lung", *i.e.* the movement back and forth of the driving rod of the bellows. On the upper strip the amount of air is registered which is sucked in and breathed out through the patient's mouth. On the left may be seen how the respiration of the "patient" (a healthy person was used for this test) takes place in the rhythm of the "iron lung". At *A* the patient tried to breathe in against the force of the "iron lung". This was found to be practically impossible: the patient can at the most hold the breath in to some extent and in this way skip a stroke of the "iron lung". Even this cannot be done for very long. At *B* the patient gives up the attempt, and gives himself up to the breathing of the "iron lung" again. At *C* the "iron lung" was stopped, and it may be seen that the patient now continues to breathe at his own slower rate and with less depth.

THE ELECTRICAL RESISTANCE OF METAL CONTACTS

by J. J. WENT.

537.311.4

The electrical resistance of contacts depends in the first instance upon the specific resistance of the material of the contacts, the hardness of the material and the contact pressure. In addition the properties of the surface of contact are also important. On the basis of these facts a study is made in this article of the methods by which a contact with a high resistance may be improved.

The interest in contact resistances is practically as old as the interest in current electricity itself. Contacts exist at numerous points in every electrotechnical apparatus, for example the contact pins of radio valves, the contact springs of switches, etc. In this article we shall discuss only permanent contacts, and shall therefore not consider such contacts as those in a relay which may be burned by sparking upon breaking the contact [1]).

Convergence resistance and transition resistance

When two completely clean pieces of metal are brought into contact with each other, there will be electrical contact at not more than three points when the contact pressure is extremely small. When the pressure is increased the material becomes elastically deformed and the contact points become contact surfaces, and their number may be greater than three. Upon further increase of pressure a plastic deformation is obtained in addition to the elastic one, so that the area of the surface of contact increases until the pressure per unit of surface remains constant, namely equal to the yield value of the material. Therefore for a given material a definite size of area of mutual contact follows from the force of pressure.

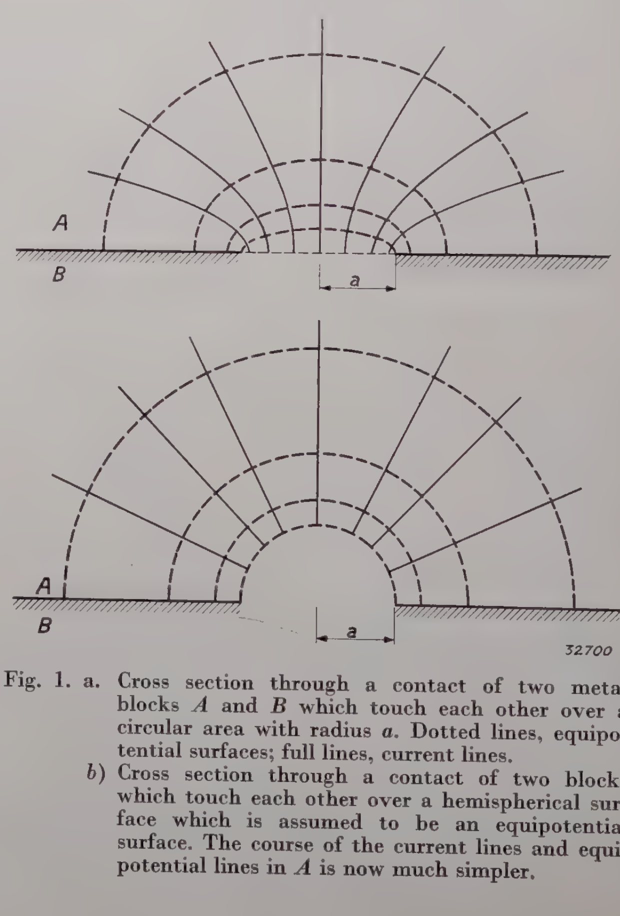
Fig. 1a shows a cross section of a circular surface of contact with a series of aequipotential lines (dotted) and a number of current lines (full lines). The area of contact itself is considered in the first place as an aequipotential surface. The other aequipotential surfaces have the form of ellipsoids which approach the sphere form with increasing distance from the area of contact.

The resistance which occurs due to the concentration of the current lines in the vicinity of the area is called the convergence resistance. This convergenc resistance is composed from the two parts R_A and R_B which arise in the two blocks A and B. If ϱ_A and ϱ_B are the specific resistances of the contact materials, and a is the radius of the area of contact then one finds for the convergence resistance:

$$R_A = \frac{\varrho_A}{4a}; \quad R_B = \frac{\varrho_B}{4a} \quad . \quad . \quad . \quad . \quad (1)$$

The derivation of the above requires a rather elaborate integration. A more specialized picture of the area of contact, as given in *fig. 1b*, can, however, be treated very simply, and gives the same result except for a numerical factor. Let us assume that the material B projects into A, so that the surface of contact has the form of a hemisphere. Let us further assume that the specific resistance of material B is so small in comparison with that of A that it may be neglected, so that the spherical surface of contact may be considered as an equipotential surface. These two assumptions will have a merely minor influence on the convergence resistance in material A.

In order to calculate the resistance of this model we must know the course of the current lines. Because of the symmetry of the model these lines have a very simple course; they



a

b

Fig. 1. a. Cross section through a contact of two metal blocks A and B which touch each other over a circular area with radius a. Dotted lines, equipotential surfaces; full lines, current lines.
b) Cross section through a contact of two blocks which touch each other over a hemispherical surface which is assumed to be an equipotential surface. The course of the current lines and equipotential lines in A is now much simpler.

[1]) A large amount of data on contact resistances will be found in the literature spread over many years. A very complete investigation, in which general theoretical considerations on contact resistances are also given, will be found in an article by R. Holm, Wiss. Ver. Siemens Konz. 7, 217, 1929. This article also includes an extensive review of the literature.

radiate as straight lines from the centre of the spherical surface. The equipotential surfaces are perpendicular to the current lines and will therefore also be hemispheres concentric with the hemisphere of the surface of contact. The resistance between two of these equipotential surfaces with radii r and $r + dr$ is:

$$\mathrm{d}R = \varrho_A \frac{\mathrm{d}r}{2\pi r^2} \cdot \quad \ldots \ldots \ldots \quad (2)$$

The part of the convergence resistance in material A is obtained by integrating dR between the limits $r = a$ and $r = \infty$, as follows:

$$R_A = \varrho_A \int_a^\infty \frac{\mathrm{d}r}{2\pi r^2} = \frac{\varrho_A}{2\pi a}.$$

This result agrees with equation (1) except that the factor π must be replaced by 2.

As has already been explained above, the area of contact depends upon the force of pressure and on the mechanical properties of the material. If one assumes that the softer of the two contact materials, in as far as it makes contact, would also be loaded up to its yield value f, and that the contact takes place over a circular area with a radius a then the total force of pressure

$$F = f \cdot \pi\, a^2.$$

When a is determined and substituted in equation (1), one finds for the convergence resistance (the sum of R_A and R_B):

$$R_u = \frac{\varrho_A + \varrho_B}{4} \sqrt{\frac{f\pi}{F}} \cdot \quad \ldots \ldots \quad (3)$$

The yield value f is a material constant which is not easily determined and it is therefore better to use the easily measured hardness instead. The latter quantity is defined as the quotient of the force of pressure and the area of surface depressed when a hard steel ball or a diamond of a special shape is pressed into the material. If one neglects hardening by cold working and possible elastic deformation, hardness and yield value are equivalent [2]).

From equation (1) it follows that it is a matter of importance whether at a given pressure a single surface of contact is obtained or a number of small surfaces which together possess just as great an area as the single surface. If for example the surface of contact is divided into n equal surfaces, the total resistance is the n^{th} part of the resistance of each of the smaller surfaces of contact. Since the resistance of a single surface of contact is inversely proportional to the radius (not to the area), the resistance of each of the small surfaces is only $\sqrt{n}$ times as great as the original resistance. The total resistance has therefore been reduced by a factor $\sqrt{n}$. Our considerations therefore give a maximum value of the convergence resistance. This will, however, be quickly reached with increasing pressure since the different surfaces of contact flow together to give a single surface of contact.

In addition to the convergence resistance there is in general also a transition resistance R_0 at the surface of contact. With poorly cleaned contacts this transition resistance may completely dominate the convergence resistance, but even with well cleaned contacts there is still an R_0, which will indeed be low at room temperature generally, but which can only be removed by very long heating in a vacuum [3]).

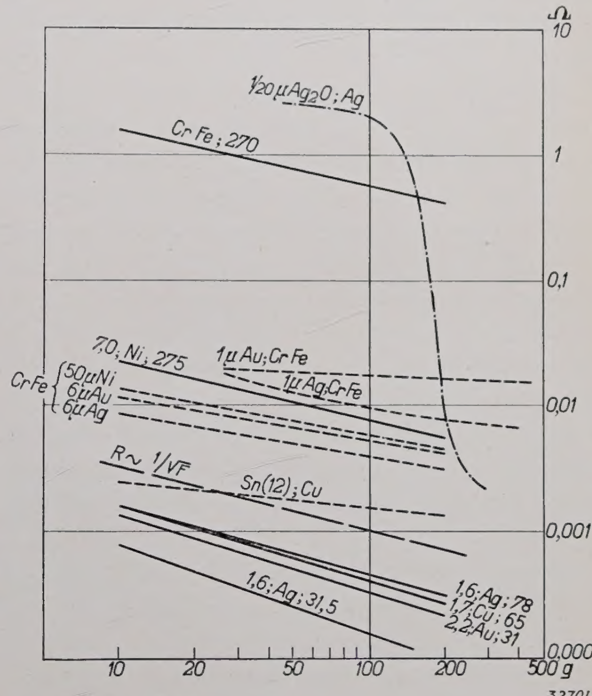


Fig. 2. Relation between contact pressure and contact resistance. Full lines, pure metals; dotted lines, metals with covering layers of another metal; dot-dash lines, silver covered with silver oxide. The number given after the symbol for the metal indicates its hardness in Vickers units; the number in front of the symbol gives the specific resistance in μ ohms cm. The heavy broken line gives the slope which is to be expected according to equation (3).

Let us for the moment assume that R_0 may be neglected in comparison with R_u. Then all the requirements for a good contact may be deduced

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[2]) On the measurement of hardness see Philips techn. Rev. **2**, 177, 1937. An exact numerical correlation between hardness and yield value cannot be attained because the material is loaded in a somewhat different way in hardness measurements and in the direct determination of a yield value. It may, however, be expected that by using the hardness instead of f, the truth will be more nearly approached than by use of the yield value, since the loading of a point of contact closely resembles the loading applied in the measurement of hardness.

[3]) R. Holm and W. Meissner, Z. Phys. **74**, 715, 1932.

from equation (3). A material must be chosen with low specific resistance and slight hardness, while the construction of the contact must allow the use of high contact pressures (100 to 300 g for example).

In *fig. 2* several measurements on such contacts are given (full lines). The same kind of material was chosen for the two parts of the contacts. The measured contact resistance and the pressure are plotted logarithmically against each other. According to equation (3) the results must be straight lines with a slope of $-^1/_2$, which is actually found to be approximately true. It may furthermore be seen from the figure that not only the specific resistance but also the hardness of the contact materials has the expected influence on the contact resistance. For instance the line for hard silver lies above that for soft silver, while copper, which is somewhat softer than hard silver but a poorer conductor, coincides with hard silver. Gold which is soft is somewhat less satisfactory than soft silver, etc.

Covering layers of soft materials with high conductivity

If for some reason it is necessary to use as contact material a material having great hardness and high specific resistance, as for instance for the pins of the all glass radio valves [4]) where chrome-iron is desirable for the fusing in, such a contact can easily be improved by covering it with a thin layer of a more suitable material.

The thickness of such covering layers must be chosen so great that the greatest part of the convergence resistance is found in this layer with its low specific resistance, *i.e.* covering layers must be made which have a thickness of at least the radius of the surface of contact [5]). This is usually 10 to 50 microns.

In fig. 2 a number of examples of this sort may be seen (dotted lines). Gold and silver layers of 1 and 6 μ on chrome-iron were actually found to decrease the contact resistance very considerably, and silver, due to its low specific resistance gives somewhat better values than gold. These layers, however, are not thick enough to attain the values for pure silver and gold; the convergence resistance not only extends to greater thickness than 6 μ, but the mechanical properties of the material beneath also play a part at these thicknesses. With a nickel layer of 50 μ the influence of the layer below entirely disappears; contact resistances are even found in this case lower than those of pure nickel, due to the fact that the pure nickel in these experiments was harder than the annealed covering layer of nickel on chrome-iron. A thick layer of tin (tinned copper) is also a fairly good contact material, due to the unusual softness of tin and in spite of its fairly high specific resistance.

There is still another reason why soft materials are preferable to hard for contacts. In addition to a low contact resistance a satisfactorily constant resistance is also desired, and thus constancy must be proof against vibrations, mechanical shocks, etc. Softer materials with greater surfaces of contact for the same contact pressure are also at an advantage in this connection.

Heating of the contacts

In general the contacts will be given dimensions such that no difficulties arise from Joule heat which is developed in the surface of contact due to the convergence resistance. If, however, such difficulties should arise, then it can be deduced from equation (1) what will be the results. Upon increase of temperature the specific resistance increases, while the hardness decreases and any hardening process is reversed. It depends entirely upon the circumstances as to which of the two effects will dominate.

Fig. 3 shows for the case of chrome-iron what may happen when the current is increased and the pressure on the contact kept constant. Taking the case of a load of 20 g, the contact resistance is

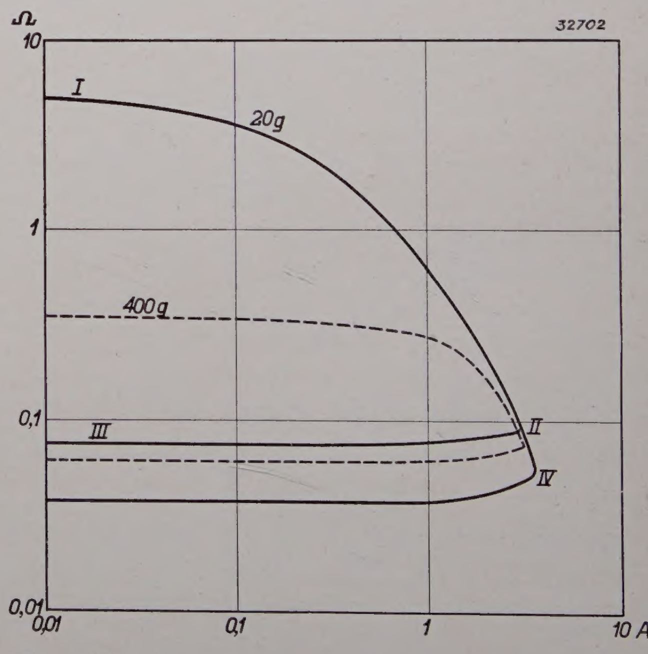

Fig. 3. Variation of the contact resistance as a function of the current at constant contact pressure of 20 g to 400 g for chrome-iron as contact material.

[4]) See Philips techn. Rev. 4, 162, 1939.

[5]) If equation (2) is integrated between the limits a and $2a$ the result is exactly one half the convergence resistance.

fairly high and much heat will therefore be developed. As a consequence the contact resistance begins to decrease at low currents already (*I* to *II*); in this case therefore the decrease in hardness dominates over the increase in the specific resistance. If beginning at *II* the current is again allowed to decrease, a curve is found which is determined solely by the temperature coefficient of the specific resistance (*II* to *III*), and which is therefore also reversible (*III* to *II*). Between *I* and *II*, therefore, practically the only change is a plastic deformation which remains upon fall in temperature. If the current is increased from *II*, the contact resistance decreases further (*II* to *IV*) and one finally reaches the melting point of the contact material where the phenomenon becomes that encountered in spot welding.

Oxidized contacts

Until now we have spoken only of clean contacts upon which there have been no oxide films. If there is such an oxide film the transition resistance R_0 may become much greater than the convergence resistance, so that the total contact resistance reaches quite a different order of magnitude. The results are not, however, always as bad as might be expected. Onemust not of course attempt to construct contacts of strongly oxidizing materials such as aluminium or lead, but an oxide film on silver does not at all prevent the attainment of a good contact. This is shown by the following experiment (see the dot-dash line in fig. 2). A silver contact is covered with a layer of silver oxide which is made thicker than can generally be expected in practical cases. With low pressures a contact resistance is found which is about 10^4 times as high as that of pure silver, but with a contact pressure of 100 to 200 g this resistance rapidly decreases. The opposite contact appears to break through the oxide layer at a number of points and one therefore obtains local contact of more or less pure metals. Although only a few per cent of the surface now makes metallic contact, quite a low value of the resistance is already reached.

It has long been known that a contact resistance can be made smaller by lubricating the contact with paraffin or oil. The most surprising results are obtained in the case of dirty or oxidized contacts because the action of the oil is based entirely on the cleaning and the keeping clean of the surfaces of contact; a perfectly clean contact is not improved by oiling.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1420: A. H. W. Aten jun., C. J. Bakker and F. A. Heyn: Transmutation of thorium by neutrons. (Nature, London, **1436**, 679, April, 1939).

Continuing the experiments referred to in Abstract No. **1410** on the production of radio-active rare gases on the disintegration of uranium nuclei by slow neutrons, a parallel investigation has been carried out with thorium, the results of which are dealt with in this paper. To obtain higher activities, the active gases are now passed over absorbent carbon instead of through water. The nature and half-life periods of the radio-active products produced from the active gases are comparable to those found with uranium. The same disintegration schemes, already given in Abstract No. **1410** for uranium, also hold for thorium.

1421: A. Bouwers and W. J. Oosterkamp: Recent Metalix tube developments. (Amer. J. Roentgenol. Radium Ther., **41**, March, 1939).

In this lecture the latest advances in the design of X-ray tubes are discussed, with special reference to a tube in which a new anode-cooling system is employed. In this tube, cooling is effected by radiation towards the middle of the tube; in tubes for diagnostic purposes which are always operated for short periods only, further cooling is effected by air convection, while in tubes used for therapeutic purposes which must be capable of running for long periods without interruption secondary cooling is provided by a current of water. For further details, reference should be made to several articles which have already appeared in this Review: The "Rotalix", Phil. techn. Rev., **3**, 292, 1938; A million-volt X-ray tube, Phil. techn. Rev., **4**, 153, June, 1939: X-ray tube for the analysis of crystal structure, Phil. techn. Rev., **3**, 259, 1938.

1422: S. Kaplan: Break-in telephony with carrier suppression (Q.S.T. Amer., **23**, 36-39, February, 1939).

A circuit containing thermionic valves is described permitting instantaneous duplex operation between two radio transmitters operating on the same carrier wave. On beginning to speak, the transmitter is automatically set in operation and the receiver switched off. A short interval in speech cuts out the transmitter and at the same time put the receiver back into service again. The system employs low-power stages, no relays being used.

1423: J. van Niekerk en H. Hofstra: De invloed van dierlijk vitamine-D bij koeien op de anti-rachitische werkzaamheid van de melk (T. Diergeneesk., **66**, 454-459, May, 1939).

Six cows received daily provitamin D of animal origin irradiated with 3 200 international units per litre of milk yield. During the fourth and fifth weeks of this diet, experiments with young rachitic rats indicated that the milk contained an average of 84 international units of antirachitic vitamin per litre. During the sixth and seventh weeks, the average vitamin content was 63 international units per litre, while ordinary milk in this area and at this season of the year contained about 20 international units per litre. On the average, therefore, 1.7 per cent of the vitamin D fed to the cows reappeared in the milk. A diet of irradiated provitamin D of animal origin is hence much more effective for increasing the vitamin-D content of the milk produced, than with irradiated ergosterin according to the literature and has roughly the same effect as with a diet of irradiated yeast.

1424: J. F. Schouten: Het mechanisme van het zien in verband met het vraagstuk der verblinding (De Auto, **36**, 750-752, May, 1939).

The principal causes of glare are discussed in this paper; *viz.*, that the eye is not a perfect camera but disperses light which results in glare, and that the sensitivity of the retina varies very considerably with the intensity of illumination falling on it, resulting in physiological or adaptative glare.

1425: W. de Groot: Luminescence decay and related phenomena (Physica, **6**, 275-290, March, 1939).

The variation of the photo-luminescence of zinc sulphides (*e.g.* ZnS-Cu) with time on periodical illumination for intervals of 5 millisecs, is investigated with the aid of a secondary electron multiplier and a cathode-ray tube. The light source consisted of a mercury-vapour capillary lamp fitted with a monochromator, and the ultra-violet radiation intensity obtained was about 0.5 watt per sq. cm. A bimolecular mechanism of luminescence in conjunction with metastable states is discussed. In conclusion, some observations concerning uranium glass are described.

1426: W. de Groot: Saturation effects in the short-duration photo-luminescence of zinc-sulphide phosphors (Physica, **6**, 393-400, May, 1939).

The intensity of the fluorescent light of several sulphide phosphors (ZnS-Cu, ZnS-Ag, ZnS/CdS-Ag and ZnS-MnS) was measured as a function of the intensity of the energising ultra-violet light. It was found that with the same total energy, the fluorescent light emitted by these substances is 5 to 10 per cent lower for a radiation energy of approximately 5 watts per sq. cm. than with a radiation density 100 times smaller. This phenomenon is not observed with uranium glass, crystals of potassium uranyl sulphate and fluorescein solution.

1427: M. J. O. Strutt: High frequency mixing and detection stages of television receivers (Wireless Eng., **16**, 174-187, April, 1939).

For details of this article, see Abstract No. **1405**.

1427A: L. W. M. Roodenburg: Vervroeging van de bloei bij Kalanchoe Blossfeldiana (Kon. Ned, Mij. Tuinb. Plantk., **13**, 145-148, 153-155 and 162-164, May, 1939).

If from the middle of August, the daily exposure to daylight of a Kalanchoe is reduced to 10 hrs. for several weeks, these pot-plants which normally only blossom during the latter half of the winter will already be in full bloom about Christmas.

1428: F. Prakke, J. L. H. Jonker and M. J. O. Strutt: A new "All glass" valve construction (Wirel. Eng. **16**, 224, May 1939).

For the contents of this article refer to Philips techn. Rev. 4, 162, June 1939.

In September 1939 appeared:

Philips Transmitting News **6**, *No. 2:*

K. Posthumus and Tj. Douma: Frequency Stability.

Shortwave telegraphy transmitter KVC 1,5/14.

W. Albricht: Pentodes on short wavelengths.